Environment Canada
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PROCEEDINGS OF THE SYMPOSIUM ON INTERBASIN TRANSFER OF WATER: IMPACTS AND RESEARCH NEEDS FOR CANADA

National Hydrology Research Centre
Centre national de recherche en hydrologie

Canadian Water Resources Association
Association canadienne des resources hydriques

COMPTES RENDUS DU SYMPOSIUM SUR LE TRANSFERT DE L'EAU ENTRE BASSINS: REPERCUSSIONS ET BESOINS DE LA RECHERCHE AU CANADA

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Editors / Editeurs
W. Nicholaichuk & F. Quinn

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FOREWORD

The volume of water transferred between drainage basins in Canada is larger than in any other country in the world. What have we learned from this experience? What more do we need to know before considering seriously any future transfers? The recent slowdown in growth of water demand for agricultural and energy production provides an opportunity to reassess economic, social and environmental realities and the limits of our predictive and management capabilities.

Scientific uncertainties related to interbasin transfer were among the most important issues recommended for further investigation by the Inquiry on Federal Water Policy. Following discussions between Environment Canada and the Canadian Water Resources Association in 1986, it was agreed to co-sponsor a national symposium which could assist government to better define its research and monitoring priorities.

The objectives of the symposium were:

- to compare experiences with different kinds of interbasin transfer projects across Canada, including hydrological morphological, engineering, biological, social, legal, economic and political aspects;
- to review the adequacy of pre-project and post-project monitoring activities in support of more comprehensive assessment of project impacts;
- to identify the data and research needed to improve our understanding of the implications of water transfer in terms of natural processes, social values and policy alternatives.

The organizing committee for the symposium consisted of T. Milne Dick (Chairman), W.E. Watt, J.T. Moenig, J.E. Fitzgibbon, Y.L. Lau, F.J. Quinn, J. Gilles, B.C. Kenney, W. Nicholaichuk, S. Hansen and B. MacEwan. The assistance of session chairmen, and others who helped with technical and social arrangements was much appreciated.

The papers included in these Proceedings were selected by a technical program committee on the basis of an extended abstract. The papers are published as submitted by the authors with minor revisions. No formal review procedures were used; accordingly any views and statements expressed are those of the authors and do not necessarily reflect the views of the Canadian Water Resources Association or the National Hydrology Research Institute.

Editors

W. Nicholaichuk & F. Quinn

Opening Remarks

INTERBASIN TRANSFER OF WATER:

IMPACTS AND RESEARCH NEEDS FOR CANADA

Dr. T. Milne Dick

Director
National Hydrology Research Institute
Inland Waters Directorate
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Saskatoon, Saskatchewan

INTERBASIN TRANSFER OF WATER:

IMPACTS AND RESEARCH NEEDS FOR CANADA

T. MILNE DICK[1]

Arrangements for this Symposium began with a collaboration between the Hydraulic Division of the National Water Research Institute (NWRI) in Burlington and the Canadian Water Resources Association (CWRA). Circumstances transferred it to Saskatoon where arrangements were made between the National Hydrology Research Institute (NHRI) in Saskatoon and CWRA.

NHRI at Saskatoon is just over one year old today. Organizing such seminars with others is going to be one of the key components in our role of communications with the hydrological and environmental sciences. Establishment of NHRI in Saskatoon will greatly improve the research attention to the key questions of the impact of climate change, northern hydrology and the impact of man on the surface and ground water systems. Last but not least, we hope to integrate biological with the traditional chemical and physical aspects of water and to address the problems of the aquatic environment in as a holistic way as possible. A fortunate arrangement is the presence of the Hydrometeorology Division of the Atmospheric Environment Service at the National Hydrology Research Centre which adds greatly to the total sum of expertise available to address environmental questions.

Ca va sans le dire, que le sujet de nos discussions pendant aujourd'hui et demain pose des problèmes scientifiques et socio économiques. Tout le monde sait bien que la disposition des nos ressources naturels au présent influencera continuellement sur la vie des Canadiens dans l'avenir. Pour cette raison, il est très important que les conséquences des décisions soient bien connues pour réduire autant que possible la possibilité d'un résultat désastreux et imprévu.

Proposals for a diversion emotes both emotional and scientific reactions. Proposals to rearrange the natural order of things will in todays world provoke action on many fronts. Therefore, engineers and hydrologists must be in position to objectively evaluate the consequences of such developments which will affect Canadians for a long time in the future.

Diversion of water is usually justified on economic grounds. However, it should be recognized that a diversion proposal may just be one solution to meet an imbalance of supply. Other strategies may meet the situation such as reducing demand or reducing system losses. Diversions are proposed or undertaken to augment or provide a supply of water or to improve the cost/benefit ratio for power developments. However, it is increasingly evident that both costs and benefits must include environmental factors in order to gain a true perspective on the project.

---

[1] Director, National Hydrology Research Institute, Saskatoon, Saskatchewan

For example, a new reservoir may cause the release of mercury which contaminates the fish with consequent disbenefits for tourism and recreation which offsets benefits obtained for power generators or navigation. Changing the river flow either in the donor or receiving basin may also result in long-term changes to sediment transport with altered habitats and river water quality. Small changes in nutrient levels of a river from a diversion may cause big changes in river algal production. Diversions may transfer diseases or biota which wreak havoc in their new environment. Greater winter flows may create transportation problems and changes because of thin ice used.

The need to consider policies of development and environment are fairly clear and have been recently promoted in the so-called Brundtland report, (Our Common Future, World Commission on Environmental Development). Both economic and environmental factors must be considered for large development works.

To have fair and balanced judgements, environmental assessments must attain equality of rigour and reliability as for engineering and economics. Advancing knowledge so that environmental assessments are reliable and quantitative should be the concern of all scientists and engineers working on water resources today. It may, if it has not already done so, introduce a new kind of engineer.

The need for research and reliable data in order to obtain sound environmental scientific knowledge and data is a major challenge and requirement as we approach the 21st century.

Comme j'ai déjà dit en anglais, le défi pour la science hydrologique et biologique dans l'avenir sera de developper les moyens de prédire les effets sur l'environnement du progrès economique. Aussi, il faut analyser une proposition également bien soit pour la génie et l'economie soit pour l'environnement.

Engineers and scientists must try to develop a rapport so that major engineering works are undertaken with a full understanding and recognition of the environmental changes consequent upon proceeding with the project. Diversions are a major long-term change in the natural order and are just one of the many impacts of man on the environment. Diversions of water from basin to basin are obviously major investments and it is important that research should provide the means to correctly evaluate the consequences of such actions.

OVERVIEW

INTERBASIN TRANSFER OF WATER

Moderator: Dr. T. Milne Dick

Director
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Environment Canada
Saskatoon, Saskatchewan

MORPHOLOGIC EFFECTS OF INTERBASIN DIVERSIONS

ROLF KELLERHALS[1] P. ENG.

ABSTRACT

The huge ice caps which covered most of Canada until some 10 000 years ago have left behind a complex drainage network that provides many opportunities for large scale storage and diversion projects and whose rivers exhibit highly variable and complex morphologies. The morphology of rivers is important because it provides the physical framework for many other river-related resources such as fisheries, recreation and navigation. By far the most important factor determining the morphology of a specific river reach is the flow regime. When it is artificially altered through interbasin diversion or regulation, morphologic changes invariably follow, but they can range from barely perceptible to dramatic for reasons that are not necessarily obvious a priori. Several important morphological processes have critical thresholds and it is the crossing of such thresholds that characterizes the interbasin diversions that have resulted in dramatic morpholgical changes. A reasonably solid theoretical basis for predicting morphological changes due to imposed flow regime changes exists only for the case of ideal alluvial rivers, and even there the predictions refer to a new equilibrium state that might take of order 10^3 to 10^4 years to achieve. Most practical predictive work has to rely extensively on comparisons with documented case histories and there are still far too few of these available to cover even the situations most commonly occurring in Canada. Séveral case histories of rivers with increased and decreased flows serve to illustrate the range of morphological changes seen in Canada and the practical difficulties of predicting these changes a priori. Systematic long-term morphological monitoring of existing diversions is essential if better predictive models are to be developed.

---

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INTRODUCTION

River channels are the result primarily of flowing water working and re-working the materials of the earth's surface. This process of channel formation is continually interacting with and being disturbed by other processes of a geological, climatic, biological and man-made nature. The end result of all these actions and interactions is the fluvial landscape as we see it now.

One legacy of the massive ice caps and valley glaciers that covered most of Canada up to some 10 000 years ago is the relative youth, geologically speaking, of most Canadian rivers. Typical features of young rivers are: bedrock rapids, gorges, lakes and narrow valleys being actively enlarged. Another, related legacy of the recent ice age, is the extreme diversity of river types, with most major rivers exhibiting many different types of morphology along their course.

A third legacy of great practical importance is the extremely deranged drainage system that offers many opportunities for large-scale flow regulation and diversion projects. Canada has been taking advantage of this for a long time. The last forty years have seen the completion of numerous large projects that are, almost without exception, serving their intended function. In many instances however, there have been some unforeseen, detrimental environmental and social consequences. Since morphological changes were often identified as the underlying cause, this has resulted in an upsurge of interest in fluvial morphology in the engineering community.

Another good reason why engineers should be interested in fluvial morphology is the fact that the fluvial landscape often contains detailed data on a river's past actions. If properly interpreted there may be far more useful information on flood levels, ice jams, log jams, channel shifting rates and aggradation or degration rates available in the field and on air photos, than could be gleaned from formal records.

Fluvial morphology can be defined as the branch of science which tries to find systematic order in the wide range of landforms associated with rivers and tries to understand the processes responsible for the formation of these landforms. The morphology of a river provides the physical framework within which many biological processes and social actions take place. Morphological change is therefore often the first link in long chains of interactions leading to results that may, at first, seem far removed from morphology. To complicate matters further, there are also feedback loops, i.e. biologicl changes resulting initially from morphological change such as vegetation encroachment into an active river channel zone, can lead to further morphological changes, such as enhanced sediment deposition.

The objective of the present paper is to discuss how and to what degree morphological changes can be predicted and to make some suggestions on how the present, rather unsatisfactory state of the art might be improved. Seven Canadian case histories are introduced to illustrate predictability with the benefit of hindsight.

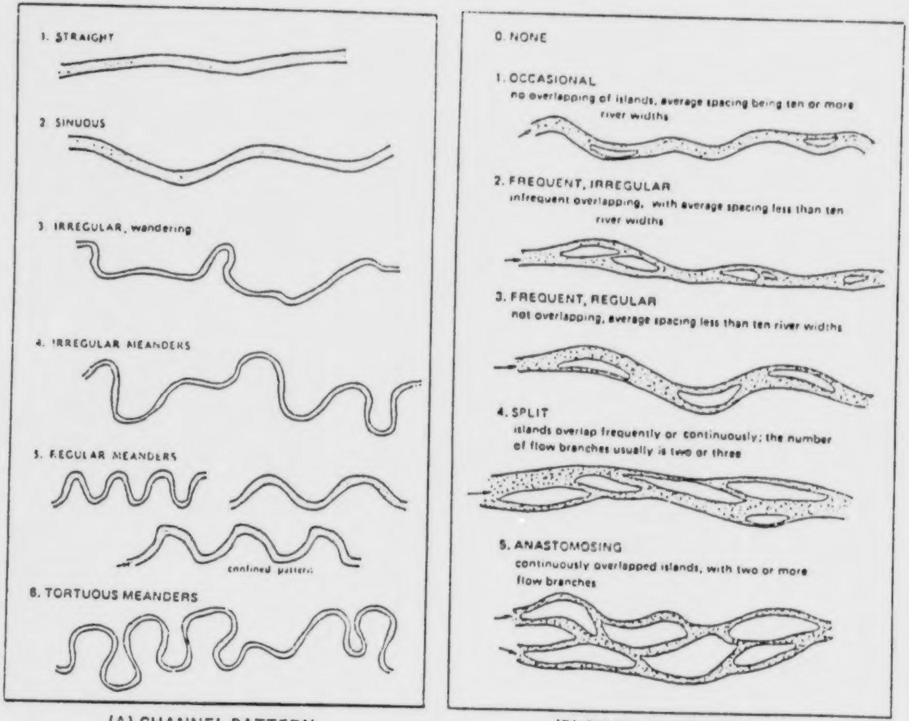
FACTORS DETERMINING RIVER MORPHOLOGY

Since few rivers have a uniform morphology from their source to the mouth, one normally has to divide them into what appears to be morphologically uniform reaches before trying to characterize their respective morphologies. Most reach breaks are associated with geological boundaries such as lake inlets or outlets, tributary confluences, or works of man such as dikes, but there are also purely river-made breaks such as the abrupt transitions from gravel beds to sand beds that occur in most rivers of the Great Northern Plains and in many deltaic reaches.

The morphology of a homogeneous river reach can be divided into many elements; some are relatively easily defined in quantitative terms, e.g. channel width, depth and area, channel and flood plain slope and meander wave length, while others are essentially descriptive and therefore more difficult to define objectively, examples being the type of meander pattern, types of river bars, types of bed forms, type and degree of channel confinement by valley walls. Considerable effort has been devoted to developing morphological classification schemes (Mollard 1973; Schumm 1977; Kellerhals, Church and Bray 1976; Kellerhals and Church 1988). Fig. 1 illustrates four aspects of the morphological classification presented in Kellerhals and Church 1988. Besides the above descriptive parameters, the full morphological description of a river reach should also include data on the discharge and sediment transport regimes, ice processes, bed and bank material, and flood plain and bank vegetation.

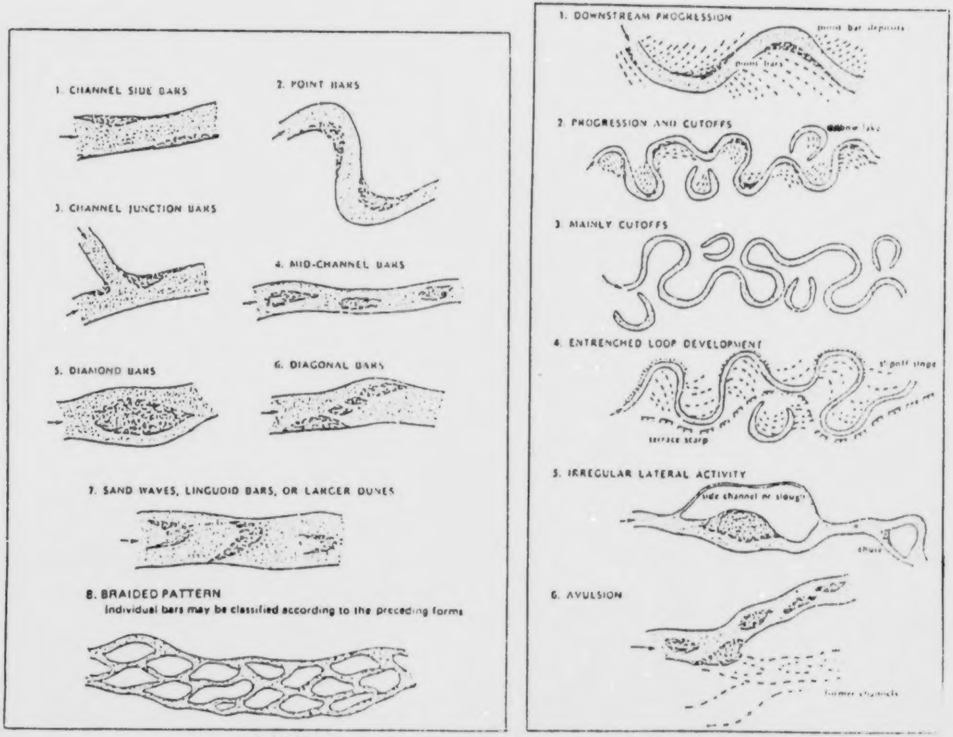
The interdependence between the many factors making up the morphology of a river reach is relatively simple and well known for the case of ideal alluvial rivers, but becomes quite intractable as soon as external factors, particularly geological ones, disburb the ideal situation. The ideal alluvial river is formed in situations where a river emerges into a wide geologic depression (e.g. a glacial lake) with a solid, fixed outlet sill. After a long period of geological stability the river will have built a flood plain across the basin and net sedimentation will cease. At this stage the morphology of the river reach across the basin will depend almost entirely on the flow and sediment transport regimes, as supplied from the upstream drainage basin. Secondary factors such as climate, flood plain vegetation and sediment petrology have only minor effects as is well illustrated by the worldwide similarity in river types.

Ideal alluvial river reaches are rare, but there are numerous sites where conditions approach a truly alluvial state, examples being infilled lake basins, upper reaches of slowly growing deltas, large fans, etc. The vast majority of Canadian Rivers are, however, not flowing on fully self-formed surfaces and are therefore not alluvial. This implies that


1. STRAIGHT
2. SINUOUS
3. IRREGULAR, wandering
4. IRREGULAR MEANDERS
5. REGULAR MEANDERS
confined pattern
6. TORTUOUS MEANDERS
0. NONE
1. OCCASIONAL
no overlapping of islands, average spacing being ten or more river widths
2. FREQUENT, IRREGULAR
infrequent overlapping, with average spacing less than ten river widths
3. FREQUENT, REGULAR
not overlapping, average spacing less than ten river widths
4. SPLIT
islands overlap frequently or continuously; the number of flow branches usually is two or three
5. ANASTOMOSING
continuously overlapped islands, with two or more flow branches

(A) CHANNEL PATTERN (B) CHANNEL ISLANDS

Fig. 1a - Classification of channel planform features (after Kellerhals and Church, 1987).


1. CHANNEL SIDE BARS
2. POINT BARS
3. CHANNEL JUNCTION BARS
4. MID-CHANNEL BARS
5. DIAMOND BARS
6. DIAGONAL BARS
7. SAND WAVES, LINGUOID BARS, OR LARGER DUNES
8. BRAIDED PATTERN
Individual bars may be classified according to the preceding forms
1. DOWNSTREAM PROGRESSION
point bar deposits
point bars
2. PROGRESSION AND CUTOFFS
oxbow lake
3. MAINLY CUTOFFS
4. ENTRENCHED LOOP DEVELOPMENT
terrace scarp
5. IRREGULAR LATERAL ACTIVITY
side channel or slough
chute
6. AVULSION
former channels

(C) BARS

(D) LATERAL ACTIVITY

Fig. 1b - Classification of channel planform features (after Kellerhals and Church, 1987).

additional factors beyond flow and sediment supply from upstream are externally imposed. Slope and bed materials are the most commonly imposed external factors, mainly because of the enormous periods of time needed to develop long alluvial surfaces. In the case of major rivers, the formation of a 100 km alluvial reach could involve periods of order 10^4 to 10^5 years, during which there would also have to be relative geologic stability. Clearly such periods of stability have not been available in the recent geologic past and most Canadian rivers are therefore flowing on surfaces (i.e. the Canadian Shield, the Northern Great Plains, the valley floors of the the Western Cordillera) that the present day rivers did not create. In most instances they have modified the surface on which they flow quite significantly, on the Great Plains, for instance, they have excavated shallow valleys, but they remain far from achieving alluvial slopes except locally for short reaches.

In practical terms the question whether a morphological feature of a river is dependent on the flow and sediment regime coming from upstream and subject to change as this upstream supply is being changed through diversion or regulation, or whether the feature should be considered externally imposed and fixed, depends mainly on the time scale of interest. Channel width, for instance, is clearly a self-formed fluvial feature, even in the extreme situation represented by bedrock canyons. Yet in trying to assess morphological changes due to a man-made interference with the upstream flow or sediment supply, width may have to be accepted as fixed if the river lacks the ability to change it within the period of interest. Alternatively, width needs to be treated as a dependent parameter if the river has the ability to change it within the period of interest. Decreased flows in an incised, stable channel immediately below a lake or a reservoir is one situation where channel width could only adjust to imposed conditions of reduced flow through gradual unravelling of the valley walls or through further incision, both processes taking thousands of years and therefore of little practical interest. The Nechako River discussed later on in the section "Case Histories" is an example of this type. Decreased flood flows in relatively unstable sand bed channels, on the other hand, can result in channel narrowing within 5 to 20 years. The South Saskatchewan River immediately below Gardiner Dam has reduced its width from 600 m to 200 m over a period of 18 years (Galey et al. 1985; Yuzyk 1987). The Platte River of Nebraska is an extreme case of width adjustment. It has lost up to 90 per cent of its channel width over a period of 100 years, mainly due to a more regulated, perennial flow regime (Eschner et al. 1983).

In general one can say that virtually all aspects of fluvial morphology depend on upstream flow and sediment supply given unlimited time to adjust, but in practical terms an increasing number of morphological parameters needs to be accepted as invariant with decreasing time of interest, with decreasing sediment load and with increasing stability of the river reach.

Efforts to quantify the relations between the independent parameters of upstream flow and sediment transport regime and the resulting fluvial morphology, or, more specifically the resulting hydraulic geometry (width, depth, slope, flow velocity) have proceeded along two separate lines. Empirical analysis of data from rivers, canals and laboratory experiments with river trays have lead to a multitude of so-called regime equations of the general form

[1] $$W = a_1 Q^{b1}$$

[2] $$d = a_2 Q^{b2}$$

in which Q is a consistently defined discharge, such as the mean annual flow, the mean annual flood or a bankfull flow; W and d are the corresponding width and depth. The exponents b_1 and b_2 are relatively constant for rivers worldwide, b_1 being close to 0.5, b_2 around 0.3 to 0.4. the coefficients a_1 and a_2 depend on other morphological parameters, particularly sediment transport, bed and bank material, but they do remain constant over many orders of magnitude of discharge, Q, for any given type of channel. Equations similar to [1] and [2] have also been proposed for channel slope and flow velocity and there are many more elaborate versions in the literature in which sediment transport or bed and bank material sizes are introduced as additional independent variables. The two main drawbacks of the regime approach are: (i) that it ignores the physical processes that form and change river channels and (ii) that it says nothing about the time needed to form regime channels.

The alternative approach to quantifying the hydraulic geometry of river channels is to use a purely physical approach based on the concept of conservation of mass (water and sediment), an equation of motion for water, a channel friction factor and a sediment transport equation. Many computer models have been developed to implement this approach, MOBED (Krishnappan 1985) being one Canadian example. An up-to-date review of the US models is presented in Dawdy and Vanoni (1986). One basic drawback of all these models is the fact that they are strictly two-dimensional. They address scour and deposition in existing channels, but cannot predict channel width, channel plan form, or many other important morphological parameters. A second problem common to all computer models is the low predictive capability of existing sediment transport equations, which is a reflection of the inadequacy of the underlying theory. White et al. (1975) compared the computed sediment transport rates based on 15 equations proposed in the literature with some 1000 sets of laboratory data and 270 sets of field observations from 11 rivers and found that only 3 equations gave predictions in the range of 0.5 to 2 times the correct value in more than 50 per cent of the cases.

PREDICTING MORPHOLOGICAL CHANGES

The practical problem of interest here normally involves some engineering project that will modify the flow and sediment transport regimes of various river reaches. The desired result is a detailed description of morphological changes and the associated rates of change. A description of normal data requirements for such predictions is given in Kellerhals (1982). One common obstacle is that of obtaining useful and reliable post-project flow predictions; particularly the important future project operation under flood conditions may not be adequately thought out at an early stage.

Pre-project river morphology can be readily determined through surveys following procedures given in Neill and Galay (1967), Thomas (1977) and Kellerhals et al. (1976).

A problem of increasing importance in Canada is the fact that the flow regimes of many major rivers are already significantly affected by projects built during the last few decades and the existing channel morphologies are therefore in the process of adjusting. The original "natural" morphology was likely not documented and may only be available on old maps and air photos. Any morphological changes due to future projects will be incremental to on-going and rather ill-defined changes. The spectre of imminent, major climatic changes adds further complications.

The first few kilometres of river immediately below a project site (e.g. dam site, point of entry of a diversion) can be studied with existing computer models such as MOBED (Krishnappan 1986; Galay et al. 1985) as long as there is an incised, well-defined channel that justifies the assumption of unchanged channel width. However, if channel width is likely to change, or if a major change in morphologic channel type is a possibility (e.g. conversion from a braided channel system to a single channel, See Fig. 1), those changes would have to be guessed a priori, on the basis of experience elsewhere, before the two dimensional computer models could be applied.

The South Saskatchewan River below Gardiner Dam, which is discussed in the above two references and in Yuzyk (1987), illustrates this point very well. Channel morphology has been documented at regular intervals since the project became operational in 1964. The observed lowering of the channel bed over the first few kilometres below the dam can be computer modelled, but the fact that the channel width shrank from 600 m to 200 m cannot. For satisfactory model results the width reduction does, however, have to be included in the model. The sediment-free releases from Gardiner Dam are also causing bed armouring (the bed material is being winnowed of its finer fractions) and that, too, creates modelling problems. A priori application of the computer models, had they existed in 1964, would not have produced reliable results.

A few kilometres beyond a project site, the reliability of computer models tends to drop off rapidly because of accumulating inaccuracies. Predictions of morphological change then have to rely entirely on the judicious application of empirical concepts. The regime equation discussed above can provide some guidance in situations where the imposed changes are relatively small (around ± 30 per cent or less), but only if there is the physical ability to effect change within reasonable time.

Larger imposed changes are increasingly likely to cross some critical threshold that may lead to an entirely different, new morphology. In such cases even the direction of change may be uncertain. Several case histories of this type are illustrated in the next section.

Following earlier work by Schumm (1977), Kellerhals and Church (1988) have recently developed a table that indicates the expected direction of change in several morphological parameters downstream of major water resources projects affecting the three variables; discharge (Q), bed material load (Q_{bm}), and wash load (Q_w). The table is reproduced here in slightly modified form as Table 1. The morphological parameters are explained in the legend. The reliability of the table entries varies from well established facts to unsubstantiated judgments by the authors. The rationale for Table 1 is best illustrated with some Canadian case histories.

CASE HISTORIES

In 1978 in the course of environmental studies for the proposed McGregor diversion, BC Hydro assembled morphological data on Canadian interbasin diversions (Kellerhals et al. 1979). The study had an immediate impact on Phase 2 of the McGregor diversion studies. The predicted morphological impact on the receiving valley (Parsnip River) was changed from the extensive, permanent inundation of the valley floor predicted in the Stage 1 studies, to inundation followed by channel incision and the eventual draining of the flood plain marshes. Since publication of the compilation of Kellerhals et al. (1979), some major new diversions have been carried out and several old ones have been "discovered" and studied. A recent listing of Canadian interbasin diversions is available in Quinn (1987), but it omits a few morphologically important projects. There is no recent, complete compilation of morphological data and such a task is beyond the scope of the present paper. The objective here is limited to illustrating a few basic concepts with Canadian case histories.

Receiving Rivers

In terms of Table 1, the change along receiving rivers can be stated as Q^+. The relative wash load, q_w, may be up or down, depending on the type of water being diverted. The relative bed material load, q_{bm}, will likely be down near the point of entry into the receiving river if water is diverted through a reservoir, but extensive erosion often sends q_{bm} to very high levels only a short distance below the point of entry.

Elk River, Vancouver Island (Karanka and Kellerhals, 1980). In the 1930's this was a stable, anastamosed gravel bed channel flowing on a broad flood plain covered in tall first growth timber. Clearcutting of the flood plain in the early forties followed by a landslide into a headwater lake, led to increased channel instability and channel widening from 40 m

Table 1: Qualitative changes in major morphologic parameters for selected imposed changes.

Case	Imposed changes			Probable direction of resulting change								
No.	Q	q_{bm}	q_w	w	d	S	D_{50}	F	λ	P	M	Remarks
1	+	-	-	+	+	-	+	-/±	+	+	-	Assuming no change in Q_{bm} and Q_w
2	-	+	+	-	-	+	-	-/+	-	-	+	
3		+		+	-	+	±	+	?	-	-	Change in D_{50} depends on type of material supplied from upstream
4		-		-	+	?	+	-	?	+	+	
5			+	-	+	?	-	-	?	+	+	
6			-	+	-	?	+	+	?	-	-	
7	-	-	-	-	-/±	-	±	±	-	+	-	Change in d depends upon balance between Q and q_{bm}
8	-	-	+	-	-/±	-	±	±	-	+	+	
9	+	+	+	+	+	±	±	±	+	±	±	
10	+	+	-	+	+	±	±	+	+	-	-	

Table 1 Continued

Legend:

Q	Channel-forming discharge, approximately 2- to 10-year flood
q_{bm}	Relative bed material load, Q_{bm}/Q
q_w	Relative washload, Q_w/Q
w	Channel width
d	Channel depth
S	Channel slope
D_{50}	Median bed material size
F	Width/depth ratio
λ	Meander wavelength
P	Sinuosity
M	Percent silt and clay in channel perimeter materials

Note:

All channel dimensions are associated with discharge Q.

If initial changes are thought to be different from long-term changes they are separated by /. If change can occur in either direction it is shown as ±, with the more probable direction emphasized as $\overset{\boldsymbol{+}}{-}$ or $\overset{+}{\boldsymbol{-}}$.

Imposed changes are assumed to be relatively large but not large enough to change the order of magnitude of the affected parameter.

to 70 m. When BC Hydro increased the drainage area by 30 per cent ($\sim$30 km^2) with the uncontrolled diversion of Crest Creek and also added a controlled diversion of up to 8 m^3/s from the Heber River, the river increased its width from 70 to 150 m over a period of some 13 years and changed to an unstable, braided morphology. Since 1970 the channel is beginning to incise at the upper end of the flood plain reach and is becoming much narrower and more stable there. Clearly the river is trying to lower its slope, but due to the vast volume of gravel that needs to be moved to do so it could take hundreds of years.

Initially the slope may even have increased due to straightening of the channel. The eventual outcome will likely be a somewhat incised, stable, single channel. In terms of Table 1 the initial change due to the Crest Creek diversion was $W^+,d?,S^+,D_{50}?,F^+,\lambda^+,P^-,M^-$, but the eventual direction of change is towards $W^+,d^+,S^-,D_{50}^+,F^+,\lambda^+,P?,M?$. The diversion did not lead to the crossing of any major threshold and all morphological changes have been gradual.

Kemano River. The Kemano River on the northern B.C. coast is another example of an unstable gravel bed river receiving added flows from a hydroelectric development (Envirocon 1984, Vol. 2; Kellerhals and Church 1988). This diversion is much larger in terms of mean flows, but fully controlled and therefore not as effective under flood conditions. The changes have been less obvious than those on the Elk River, but in the same general direction. Channel incision and a return to single channel flow became apparent after 20 years and remain confined to a short reach below the point of entry after 30 years of operation.

Cheslatta River, B.C. (Envirocon 1984, Vol. 2; Kellerhals et al. 1979). The original Cheslatta River was a small, meandering gravel bed stream ($W \sim 5$ m) in a shallow glacial spillway trench on the Nechako Plateau. Since 1956, all surplus flows out of Alcan's Nechako Reservoir are being discharged by the Skins Lake spillway structure across a low divide into the upper end of the Cheslatta valley with flows reaching up to 500 m^3/s. Such flows are far in excess of what might have been compatible with the flood plain slope and fluvial sediments of the original valley. The result has been rapid incision by some 5 to 15 m of a much larger, new channel into the till deposits below the old flood plain. The Cheslatta River profile is now controlled mainly by bedrock sills and by boulder rapids. Short alluvial gravel bed reaches have developed in depressions along the old valley and a significant delta has been built into Cheslatta Lake at the downstream end. Figure 2 shows the Cheslatta River in the foreground at a site where it has cut into the fan of a tributary. The tributary is also dissecting its fan in response to the lowered base level. The Cheslatta River is a typical example of a situation where a critical threshold has been crossed resulting in rapid and quite spectacular morphological changes.

In terms of Table 1, the initial changes are $W^+,d^+,S^+,D_{50}^+,F^+,\lambda^-,P^-,M^-$, but the longterm objective is S^-.

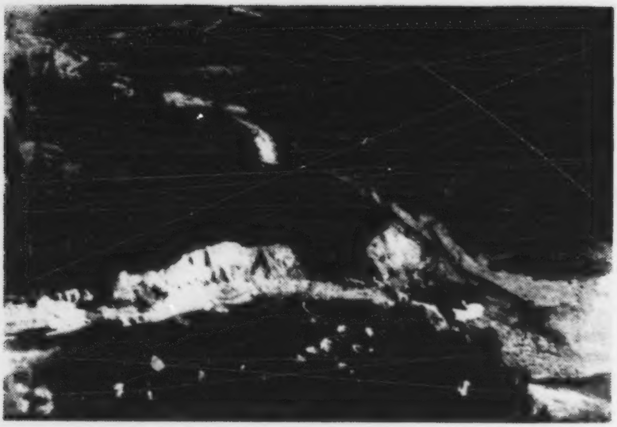


Fig. 2 - The Cheslatta River, B.C. in foreground, at a small tributary confluence.

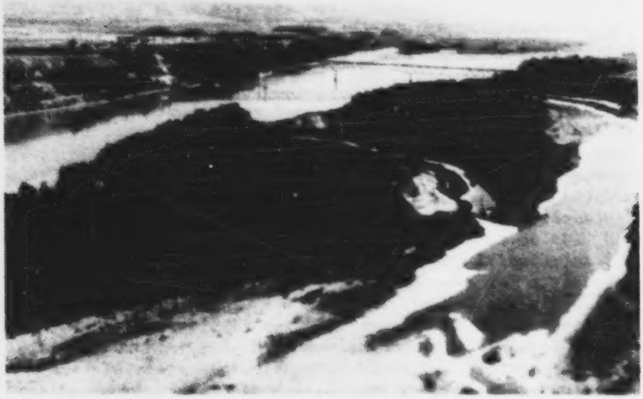


Fig. 3 - Downstream view over the Peace River, immediately below the Pine River confluence at Taylor, B.C. The vegetation on the bars and in the side channels postdates 1972, the last year of significant flood flows.

Other Canadian examples of this type are the Ogoki River (LWCNRSB 1976, Appendix 2) and Adam Creek (Kellerhals et al. 1979) in Northern Ontario, and, on a smaller scale, the canyon-line gullies formed by some irrigation return flows in Alberta. Adam Creek, where an immense gorge has been eroded through unconsolidated glacial sediments is by far the most spectacular Canadian interbasin diversion, unfortunately it may also be the most inaccessible one.

Burntwood River (Kellerhals Engineering Services Ltd. 1987). The Burntwood valley in northern Manitoba along which most of the Churchill River flows are now being diverted is an extreme example of a bedrock controlled diversion route. Along its 220 km course from Threepoint Lake, the point of entry of the diversion, to Split Lake on the Nelson River, the Burntwood River drops some 75 m, but close to 90 per cent of that drop occurs in bedrock controlled rapids. Although the river is now constantly running at flows in excess of the largest natural floods, most bedrock controls appear to be surviving and the river has therefore not been able to incise. The morphological effects have been confined mainly to flooding and problems associated with flooding, such as rapid erosion of ice-rich permafrost terrain, slope instability and floating fens. The massive ice jams predicted for the Burntwood River have not materialized so far and the latest estimates of extreme winter water levels are far below the pre-project estimates. Bank erosion is occurring locally near rapids. Comparative pre- and post-project river cross sections are unfortunately not available but it appears that the short river-like (neither lake nor rapid) reaches of the diversion are not undergoing major cross-sectional changes. The old river channel appears to be simply drowned. The fact that this contradicts the predictions made in LWCNRSB (1975) simply illustrates the unsatisfactory state of the art. The pre-project studies applied widely used empirical formulae, and predicted the development of a new, larger river channel within years. In the writer's opinion, this is still the most likely outcome, but the time frame may be one to two orders of magnitude longer than predicted.

The three receiving rivers discussed here illustrate the wide diversity of effects, but they do not nearly cover the spectrum of observed effects.

Depleted Rivers

Since the depleted rivers (Q^- on Table 1) lose some of their ability to do fluvial work, morphological changes are normally slow and unspectacular. From an environmental point of view, particularly with respect to fisheries, some changes may, however, be important and therefore need to be predicted correctly. From a morphological point of view there is great similarity between depleted rivers and highly regulated rivers, since the reduced magnitude of floods in regulated rivers also results in reduced ability to do fluvial work.

In response to numerous reports of detrimental environmental effects of depleted or regulated flows (Burt and Mundie 1986), flushing flows are now receiving considerable attention (Reiser et al. 1985). The objective of flushing flows is to maintain a certain, desirable channel morphology with reduced quantities of water by using some of the remaining water to create artificial floods.

Nechako River (Envirocon 1984; Rood 1987). The Nechako River was regulated and depleted in 1953 in the course of Alcan's Kemano project. The river exhibits a wide variety of morphologies along its course, but because it was naturally lake controlled and carried a low natural sediment load, the effects of depletion and regulation have been slow and unspectacular. Alcan's recent plans to increase power production at Kemano with additional flows to be diverted out of the Nechako River, while at the same time trying to meet the "no net loss in productivity" criterion of Fisheries and Oceans Canada, has resulted in considerable attention being given to morphologic adjustments in the Nechako River. The main effects of depletion are vegetation encroachments into the channel zone, loss of secondary channels due to sedimentation, debris jamming and vegetation encroachment and a trend towards finer bed materials with significant accumulations of fines near tributary confluences. There has also been considerable agricultural development on the flood plain that would have been impossible under natural, unregulated conditions.

The most severe fisheries problem is related to excessive summer water temperatures, a direct consequence of the river channel being far too wide for the remaining flows. Due to the small sediment load, channel narrowing is proceeding at a very slow rate, except in one short, unstable sand bed reach.

Peace River (Church and Rood 1982). The Peace River reach between Hudson Hope and the Alberta border in B.C. is interesting because it is severely regulated and because there are detailed pre-project morphological data (IPEC 1968; BC Hydro 1976). Under natural conditions this was a relatively stable, anastamosing gravel bed channel, partially incised, but with occasional flood plain segments. Regulation has reduced the morphologically active flood flows by more than 50 per cent. Both q_{bm} and q_w, which were relatively high, are now essentially zero at the head of the reach. There are, however, several heavily loaded tributaries. Below the Pine River confluence, q_{bm}^- probably changes to q_{bm}^+ and below the Beatton River even q_w^- might now be q_w^+. Changes are gradually becoming noticeable in both the river profile and in some cross sections. Pine River gravel bed material is accumulating in the Peace River near the confluence. Vegetation encroachment, wash load and wind-blown sediments are clogging many secondary channels as is illustrated on Fig. 3. Upstream of the major confluences the existing gravel bed is being coated by a slimy layer of organics and very fine sediments. To what degree a major flood with spillage at Bennett Dam would be capable or reversing these changes is unknown. In the writer's view the changes are likely permanent. One possibility for future change would be the eventual conversion of the Peace River power plants from the present base load operation to peaking, as has happened at Grand Coulee on the Columbia River. This would result in greatly increased, regulated peak flows and might bring some degree of reversal of morphological changes.

Churchill River. The Churchill River below Southern Indian Lake in Manitoba has been severely depleted since 1976, but there have been some periods of spillage at close to natural flows. The river and its tributaries have always carried very low sediment loads and the river channel is partially bedrock controlled and also well incised everywhere. The potential for morphological change is therefore low and preliminary indications are that there have, in fact, been only minimal changes. The existing channel morphology is, however, causing problems in winter. With a river channel far too large for the remaining winter flows, the river is unable to form a proper ice cover. Instead, ice gradually accumulates in the channel and Manitoba Hydro has to rela•ase considerably more water than the licenced minimum winter flows in order to assure that at least some water will make it to the town of Churchill on Hudson Bay.

CONCLUSIONS

Although the application of physically based computer models for the prediction of morphological changes remains restricted to special cases, a considerable body of empirical knowledge on morphological changes has accumulated in Canada over the last twenty years. In most situations it is now possible to predict the general direction of changes and, if a closely similar existing diversion can be examined, detailed predictions may be feasible. Predicting rates of change is more difficult because this does require some degree of modelling of the physical processes in addition to experience with case histories and also because it involves estimates of the future project operation and runoff regime, both of which are notoriously unreliable.

If a diversion crosses a critical morphological threshold and rapid changes are indicated, prediction also becomes difficult. Such situations are often associated with deep channel incision. Prediction of the outcome would require detailed knowledge of sub-surface materials which is likely to be expensive if many kilometres of river are affected.

Improved prediction requires continued efforts to monitor and document existing diversions, combined with the development of more general and practical computer models. A comprehensive summary of Canadian case histories is overdue, as is a general, worldwide synthesis of case histories.

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CLIMATE CHANGE AND WATER RESOURCES

H.G. HENGEVELD[1]

ABSTRACT

A basic assumption underlying most studies into water resource planning and management is that climate is relatively constant--that the past is a reliable predictor for the future. During the past decade, studies into the behaviour of the global climate system strongly imply that this assumption is no longer valid. A major planetary-scale climate change, induced by human activities, may in fact already be in progress. Within the next century, such changes are expected to reach proportions unprecedented in human history. As the global temperature pattern changes, so will the hemispheric wind patterns, the storm tracking, the rainfall distribution and regional soil moisture/runoff characteristics. Although the details of such changes on a regional scale are still highly uncertain, the implications for long-term water resource planning are profound. This paper will review the scientific basis for climate change projections, present a range of possible climate scenarios for Canada that may emerge in coming decades and identify some of the implications for water resource demand and management.

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INTRODUCTION

The vulnerability of societies to changes in their local climates is not a new problem. Historical records provide abundant anecdotal examples of disasters that have resulted from the unexpected onset of persistent droughts, the rampages of severe flooding or the settling in of long periods of cold and wet summers. On the other hand these societies have often benefited from particularly benign periods of climate. The discovery and settlement of Iceland and Greenland during the medieval warm period a millenia ago is an excellent example.

However, mankind's ability to cause large changes in global climate is an unprecendented, 20th century problem. Although humans have almost constantly changed their local surroundings as part of their social and economic development, never before has this experimentation reached the level of advancement or magnitude sufficient to cause environmental changes on continental or larger scales. It has now reached that level. The most worrisome aspects of this global experiment, which is significantly altering the composition of our life-supporting atmosphere, are that it is unintentional, unplanned and uncontrolled, and that our ability to predict the consequences is still so inadequate. Related climatic changes, a derivative of this experimentation, will present a major challenge for human adaptation and response.

This paper will review some of the scientific evidence which provides the basis for concern about global climate change and the results of a number of studies into how such changes may affect our regional climates. It will follow with a discussion of possible implications for Canada's water resources and their long-term management.

THE CHANGING GLOBAL GREENHOUSE

Atmospheric Composition

Our planetary atmosphere is ideally suited for life. It has an abundance of oxygen (21%), a protective layer of ozone in the stratosphere to shield us from harmful ultraviolet solar radiation, and significant amounts of carbon dioxide and water essential for the basic needs of plants and animals. Earth is also the only planet of our solar system to maintain surface temperatures within the range of liquid water. The major reason for this ideal temperature range is the presence of an atmospheric greenhouse effect. It is caused by a number of radiatively active trace gases with combined concentrations of less than 1% of the atmosphere.

Other than highly variable water vapour, the most abundant "greenhouse" gas is carbon dioxide (CO_2), with a pre-industrial concentration of approximately 280 parts per million (ppm) by volume. Other such gases include methane (CH_4) at about 1 ppm, nitrous oxide (N_2O) at 0.3 ppm and tropospheric ozone (variable). These greenhouse gases have minimal effects on the total solar energy passing downward through the earth's atmosphere. However, they delay the release of infrared heat energy from the earth's surface and lower atmosphere towards space by absorbing this radiation and re-emitting much of it back toward's the lower atmosphere and surface. Collectively these gases provide a natural insulating blanket around the planet which keeps it livable. Despite the successive transition of ice ages and interglacials during the past millions of years, they have helped to keep the average annual surface temperatures within a range of 10°C. Without them, this range would be much greater and average temperatures would be similar to that of the lunar surface, some 30°C colder.

Our unintentional 20th century experiment with the planetary atmosphere is now beginning to change this "ideal" system. Since the onset of the industrial revolution in the 18th century, atmospheric CO_2 concentrations have increased 25%, methane has increased by some 90%, nitrous oxide and tropospheric ozone are becoming more abundant and new man-made greenhouse gases such as chlorofluorocarbons are being added to the atmosphere. For most of these gases, the rates at which their concentrations are rising are accelerating. The primary sources for these increases include: combustion of coal, oil and gas for energy (CO_2, N_2O); deforestation (CO_2); agricultural processes (CO_2, N_2O), industrial processes (CO_2, CFC_s); increasing global population of ruminant animals and rice paddy acreage (CH_4); and urban smog (CH_4, O_3). Future trends in concentrations of these gases are therefore highly dependent on rather unpredictable global patterns of human behaviour. It follows that projections for these trends must be accepted and interpreted with caution. However, a continued increase in concentrations of greenhouse gases appears inevitable, likely attaining levels unprecedented in human history. Best estimates for CO_2 suggest a doubling (2 x CO_2) over pre-industrial levels, and hence a major enhancement in the global greenhouse effect, will likely occur towards the latter part of the next century. Other greenhouse gases, which in most cases are much lower in concentration than CO_2 but more potent, molecule-for-molecule, as greenhouse gases, appear likely to increase more rapidly. Collectively they may add to the effects of higher CO_2 levels sufficiently to advance the time of an enhanced greenhouse effect equivalent to 2 x CO_2 by 2035 to 2050 AD.

Global Climate Change

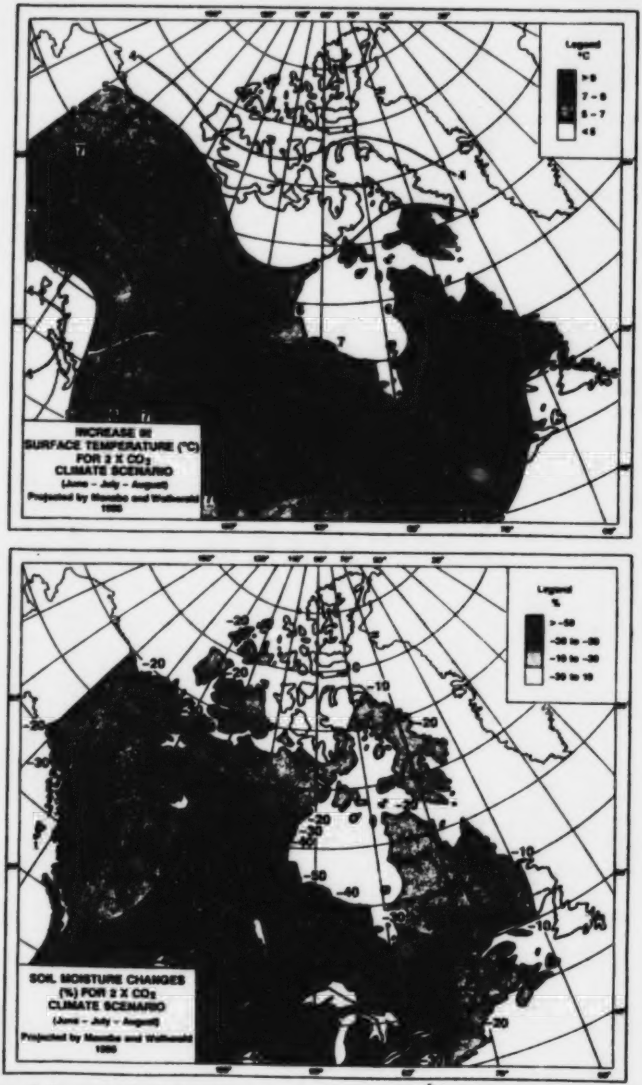
Atmospheric modellers do not as yet agree on the magnitude of the net climatic changes that would result from an enhanced greenhouse effect. Nor do they agree on the regional characteristics of such changes. However, there is a consensus that such changes will be large, significantly amplified towards polar regions in fall, winter and spring seasons and accompanied by major adjustments in storm tracking and global rainfall patterns. The range of estimates for the average global surface temperature rise for a CO_2 doubling varies from 1°C to 5°C and higher. Projections for winter

Arctic warming exceed 10°C. Most model results also suggest a migration of mid-latitude North American storm tracking northward, resulting in a drier mid-continent and a wetter sub-Arctic. Such changes would likely exceed any natural variation of global climate during the past 10,000 years. Paleoscience studies into past terrestrial climates appear to support the significance of such changes. They suggest that the medieval warm period 1000 years ago (+1°C) and the peak of the current interglacial some 6-8000 years ago (+1.5°) displayed very large changes in global water resources and hence vegetation patterns.

The most advanced climate models currently being employed for climate change experiments are three-dimensional General Circulation Models (GCMs). These models attempt to simulate the real climate system and its behaviour by including many of the key feedback processes such as cloud cover, hydrological cycles and snow and ice cover into a geophysical model of an ocean-atmosphere system. They are very complex and require the most advanced computing system available to run. Unfortunately, despite their complexity, they remain as yet very limited approximations of the real climate system. Hence results of experiments with these models must at this time still be considered unreliable. Climate change scenarios emerging from these experiments should be regarded as broad scale projections of plausible scenarios of climates to come.

Recent 2 x CO_2 experiments with GCMs appear to support the broad points of consensus identified in the preceding paragraphs. Their results indicate a range of global 2 x CO_2 warming between 3.5 and 4.2°C. Results extracted from one of these experiments, conducted by the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey (Manabe and Wetherald, 1986), are shown in Figure 1. The figure depicts the projected 2 x CO_2 summer season climate change for Canada. The dominant features of the scenario are the intense summer warming over southern Canada, centred over Manitoba, and the accompanying dramatic reduction in soil moisture. The authors explain these features are follows: Earlier snow melt and runoff results in an advanced start to the drier spring/summer season. Drier soils provide less moisture for convective cloud, hence less cloud cover and more solar insolation at the surface. Because of reduced soil moisture more of the solar energy is converted into sensible heat and less into latent heat. The increased surface temperature in turn accelerates the drying out process.

Although Figure 1 is a credible scenario, its unreliability as a prediction is demonstrated when compared with results from an earlier experiment conducted with the same model but with cloud cover prescribed, rather than responsive (Manabe et al, 1981). In that scenario, a 2 x CO_2 summer time warming in southern Canada varied between 2 and 4°C, with much more modest decreases in soil moisture (Hengeveld and Street, 1985). Figure 2 further illustrates the regional and seasonal disagreement between various GCM experiments, particularly with regards to precipitation. The comparison is between the fixed cloud GFDL experiment and GCM experiments conducted by the Goddard Institute for Space Studies (GISS) and the National Centre for Atmospheric Research (NCAR). The comparison was undertaken on a regional and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°C
>8
7 - 8
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<6
INCREASE IN
SURFACE TEMPERATURE (°C)
FOR 2 X CO2
CLIMATE SCENARIO
(June - July - August)
Projected by Manabe and Wetherald
1986
4
6
7
Legend
%
> -50
-30 to -50
-10 to -30
-10 to 10
SOIL MOISTURE CHANGES
(%) FOR 2 X CO2
CLIMATE SCENARIO
(June - July - August)
Projected by Manabe and Wetherald
1986
-20
-10
-30
-40
-50

Figure I. Scenarios for $2XCO_2$ type climate over Canada, as projected by GFDL, 1986.

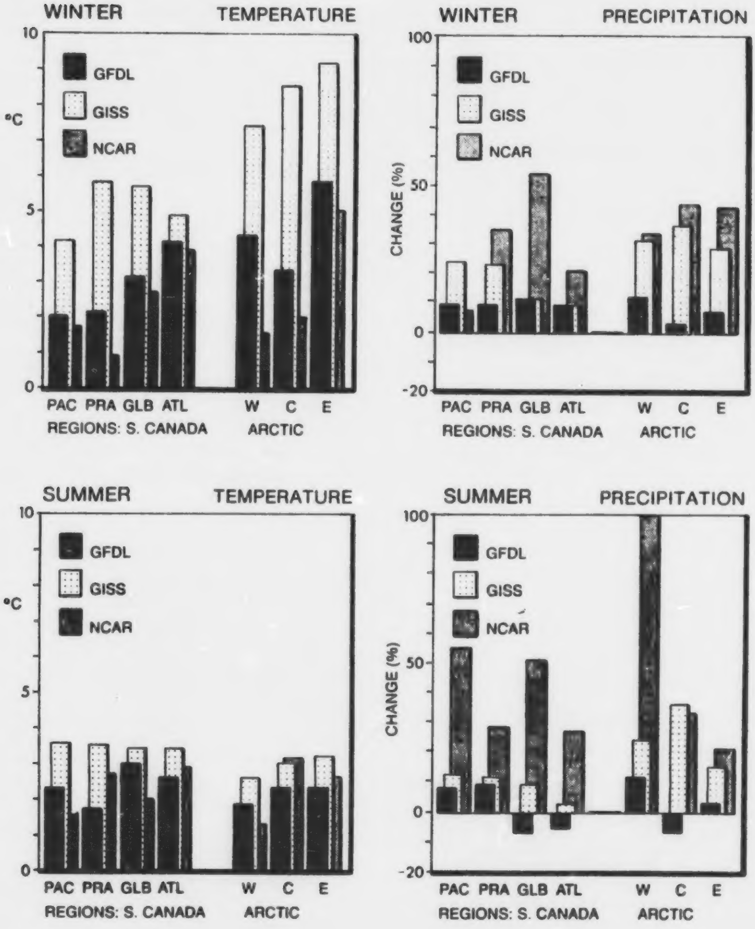

Figure 2. Regional intercomparison of $2xCO_2$ climate change scenarios for Canada.

seasonal basis in order to reduce spatial and temporal noise evident within the climate model outputs. For the summer season, all three scenarios suggest a modest but consistent 1.5 to 3.5°C warming over all regions of Canada, including those of the Arctic. For precipitation, however, the NCAR results indicate high increases in the Pacific (PAC), Great Lakes Basin (GLB) and western Arctic regions and significant increases elsewhere. The GISS scenario suggests small increases throughout southern Canada, while GFDL outputs show small increases or decreases throughout the country. The winter scenarios appear to show less, although still significant, disagreement for precipitation but display a greater range for estimated temperatures increases. All models agree that climate warming is greater in winter and in Arctic regions.

Extreme Events

The GCM scenarios for 2 x CO_2 type climates, while uncertain provide clear indications as to the probable directions of the average surface climate in the decades to come. However, humans are much more vulnerable to the occurrence of extreme events than to gradual shifts in climate. These events often bring with them hardship and calamity and generally exceed our tolerance for climate variability. They are also often unpredictable. Hence it is important to understand how the frequency and severity of extreme events would change within the above climate change scenarios. To-date GCM modellers have paid little attention to the question of climate variability within climate change. One approach to a preliminary assessment of extreme event statistics is to analyze the population distribution of climatic events over the past 30 years and adjust these populations by the changes projected by the GCM scenarios. Standard deviation of the population is assumed constant. When applied to the analysis of frequencies of July heat spells in Saskatoon, for example, this technique indicates that days with temperatures exceeding 31.1°C (the upper decile) over a 30 year period, now

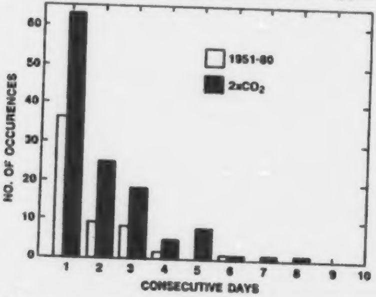

Figure 3. Frequency of Saskatoon July heat waves exceeding daily maximum of 31.1°C, over a 30 year period.

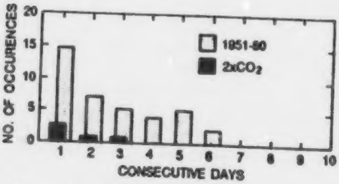

Figure 4. Frequency of Saskatoon January cold snaps reaching daily minimum of -35.6°C or less, over a 30 year period

totalling 100 days, would more than double to 248 days in the event of a 3.3°C warming (Figure 3). While heat spells of more than 3 days occurred only 3 times in the past 30 years, they would occur 16 times during a similar period under the warmer climate scenario. Conversely, January cold snaps of -35.6°C or lower would decrease from a total of 96 accumulated days for 1951-80 to 8 days for a similar 30 year period under a 6.1°C winter warming (Figure 4).

IMPLICATIONS FOR WATER RESOURCES

Water Supply

Although in many respects uncertain, several clear conclusions important to water supply issues emerge out of the CO_2-enhanced climate change scenarios. These include that:

- CO_2 concentrations will continue to increase and likely double before 2100 AD;
- a global warming of between 1° and 5°C is likely by 2050 AD. Within Canada, winter temperatures could increase by 3-6°C in the south and up to 16°C in the Arctic. Summer temperatures would increase most in the southern part of Canada, possibly by as much as 9°C.
- related changes in storm tracking and precipitation patterns will be variable but are likely to result in substantially increased amounts in the north and modest increases in the south. During summer and fall some southern regions could experience decreases.

Several methods can be used to assess the implications of the above conclusions on water resource issues. Some studies use single climate change studies as "what if" case studies to assess the sensitivity of water resources to variations in climate. Others have used multiple scenarios in attempt to find a common trend among the scenarios. Finally, a number of studies have also been devoted to the direct effect of higher CO_2 concentrations on plant water use efficiency and hence hydrology. Following are just a few of the conclusions derived from these studies:

1) Great Lakes Basin water supply, and hence lake levels, are likely to decrease significantly under typical warmer climate scenarios. As summer temperatures increase, greater evaporation/evapotranspiration appears more than adequate to offset increased rainfall suggested by most scenarios. Decreases in net basin supply of up to 21% are plausible. (Cohen, 1987; Howe et al, 1985)
2) For southern Saskatchewan, average climates under the 2 x CO_2 GISS scenario should become moister (+1 to +13% increase in precipitation effectiveness). Droughts would, however, become more frequent and more severe (Table 1). If a scenario with GISS temperature changes only is

used, the climate becomes drier (10 to 12% decrease in precipitation effectiveness) and frequency of droughts increases from 3 to 39.6%. Droughts would also be more severe.

Table 1. Implications of climatic change for South Saskatchewan droughtiness (adapted from Williams et al, 1987).

Parameter	1950-82	GISS $2xCO_2$ (T+P)	GISS $2xCO_2$ (T only)
Degree-days	—	+48 to +53%	+48 to +53%
Precipitation Effectiveness	—	+1 to +13%	-10 to -12%
Wind Erosion Potential	—	-14%	+26%
Severe Drought ($PDI<-6$)			
Frequency (%)	0.1	0.9	10.8
Return Period (yrs)	15 to 35	8.5 to 17.5	—
Drought ($-6 \leq PDI \leq 4$)			
Frequency (%)	3	9.1	39.6
Return Period (yrs)	6.5 to 10	4 to 6	—

3) In northern Quebec, net basin water supplies under both GISS and GFDL type scenarios may increase by 7 to 20% (Singh et al. 1987)

4) A possible one-metre rise in global sea levels would be a major concern to coastal fresh water supplies (Stokoe et al, 1987)

5) Based on controlled chamber experiments, increased CO_2 reduces water transpiration per unit leaf area of most plants due to partial closure of leaf stomata. This effect could significantly increase plant drought tolerance. It is unlikely, however, that this increased water use efficiency will significantly increase surface runoff characteristics, since increased leaf area may offset the increased per unit area efficiency to leave total plant water use unchanged (Arthur et al, 1985; Bolin et al, 1986).

Socio-Economic Effects

Much of Canadian economic activity is water resource dependent. Marine transportation depends on water levels, hydro-electric power generation is affected by streamflow and agriculture relies on adequate availability of soil moisture and/or water resources for irrigation. Many industries require abundant water supplies for cooling and manufacturing processes while municipalities need high quality water for public consumption. Hence changes in water resource distributions have major economic implications for almost all Canadian economic sectors. Some of the economic impacts, as estimated in the studies discussed in the preceding section, are summarized in Table 2. These impacts include the effects of longer, warmer growing seasons.

Table 2. Some possible economic effects of climatic change. (Allsop and Cohen, 1986)

Economic Activity	Potential Economic Effect (typical 2 x CO_2 scenario)
Great Lakes Commercial Navigation	-\$10 to -\$27 million/year
Great Lakes Basin Hydro-Electricity Generation	-\$34 to -\$65 million/year (-2.2 to -4. TWh)
Ontario Agriculture	-\$107 million/year
Southern Saskatchewan Spring Wheat	-\$18 to -28%
Quebec Hydro-Electricity Generation	+9.2 to 9.5 Twh

CONCLUSIONS

Two primary conclusions emerge from the preceding discussion. First, Canada's climate over the coming decades will be substantially different from that of today. It will be much warmer. Some areas will be wetter, others drier. Secondly, our natural water resources will undergo a redistribution, with less in the south and more in the north a probable outcome. Related economic implications are very significant.

These conclusions, imprecise as they may be, are important to water policy planners today. Many of our emerging water policies have time horizons similar to that of major climate changes and are highly sensitive to any changes in water resources patterns. Hence the time for including consideration of the possible consequences of climate change in water policy planning is obviously now.

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NORTHERN VALUES AND VISIONS

Managing the Water Resources of the Northwest Territories

J. W. BOURQUE[1]

ABSTRACT

The Northwest Territories, which contains almost 30% of Canada's total freshwater resources, is generally perceived as having enough water for all users. There are many factors, however, that limit water availability and use in the north. The fact that a large portion of the water is frozen almost year-round makes it difficult to use in most industrial and domestic situations. Low levels of precipitation in the more northerly areas of the Northwest Teritories make many of these areas a virtual desert and replenishment of water sources slow. The slow biological degradation of pollutants due to low temperatures can also lend to decreasing water supplies.

Traditionally, the waters of the Northwest Territories were looked upon by people of the north as a place to obtain food or as a means of transportation. Today, many northerners still maintain a close relationship with the land and its water through fishing, trapping, hunting, and recreational activities. This makes clean, unobstructed water a very important issue to the people of the north. With the increase in mining, petroleum and hydro-electric activities in the last 40 years, many people have concerns about a continuous supply of clean water.

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To ensure that the waters of the Northwest Territories are kept clean the Federal and Territorial Governments have established licensing and regulatory agencies to maintain and monitor water quality. Many of these agencies are presently with the federal government but it is expected that the responsibility for inland water resources will devolve to the Territorial government in the next few years. A Water Policy for the Northwest Territories is also close to completion. These developments will allow the Territorial Government more control over the uses of northern waters and allow them to better protect these waters for future generations.

INTRODUCTION

The total area of the Northwest Territories represents about one third of Canada. This also includes approximately thirty percent of our nation's water. The water resources of the Northwest Territories are important to all of us. Furthermore, to me, the conservation of our resources means that my grandchildren and their grandchildren in the future will all be able to drink from the same clear streams that I do today.

Purpose

The purpose of my paper is:

1. To give a brief description of the water resources of the Northwest Territories;

2. To provide an overview of the Government of the Northwest Territories draft Water Management Policy.

3. To discuss efforts in establishing Transboundary Water Management Agreements with neighbouring jurisdictions.

NORTHWEST TERRITORIES WATER RESOURCES

The North's water resources continue to provide the foundation for our economic activity as they have in the past. The Bruntland Commission report on the Environment and the Economy has confirmed what northerners had already known. Conservation and development should proceed hand in hand.

Traditionally, the lakes and rivers of the Northwest Territories have always been looked upon as an important resource. Native peoples, fur traders and explorers were dependent on the rivers and lakes for transportation. Survival depended on fishing, trapping, hunting, and fresh water supplies.

This traditional use of the water has been passed on to the generations of today. The livelihood and culture of many northern residents, particularly the native people, are dependent upon opportunities to hunt, trap and fish. In many communities, wildlife-based activities provide the sole economic opportunity. Today these traditional activities represent 50 million dollars within our Northwest Territorial economy.

The spiritual or aesthetic value that people have placed on the land and waters has become economically important through tourism.

Studies by Travel Arctic show that during the four summer months of 1987 another $50 million was spent by the 52,000 visitors to the Northwest Territories. The recent canoe trip by Prince Andrew and Lady Ferguson on the Thelon River emphasizes the growing awareness that the north has special areas which must be maintained in their natural state for future generations. I might also mention that a northern based company has successfully marketed "Arctic Ice Water" in the south.

Fortunately, water resources in the north have been relatively untouched by industrial and municipal uses. Communities, mines and other industrial users are, for the most part, widely dispersed and strictly regulated. Water managers have an opportunity to closely monitor water usage and apply the lessons learned in other jurisdictions. As well, the dependence on the renewable resource economy by northern residents ensures that the protection of the water resources for use by fish and wildlife is a primary goal of northern water managers.

I am the Deputy Minister of Renewable Resources for the Government of the Northwest Territories. I am also a former trapper and spent much time on the land. From both of these perspectives I would like to bring to your attention the major water resource issues of concern in the north. They are the potential for altered water flow in the Mackenzie River Basin and increasing water pollution.

These issues have the potential to seriously affect the use of our water resources by:

- fish, waterfowl and wildlife
- native peoples
- transportation
- tourism and resource development

OVERVIEW OF THE NORTHWEST TERRITORIES WATER MANAGEMENT POLICY

For the last 40 years, resource development activities in the Northwest Territories have increased tremendously. Mining, oil exploration, hydro-electric developments and domestic use have benefitted from northern water resources. They have also caused localized water problems in some areas. Over the past several years, our government has been working co-operatively with the federal government to protect the water resource. We have tried to ensure that development projects do not affect the use of northern waters by fish and wildlife now, or in the future.

The time has arrived when we as a government must do more than just try to be sure that water is conserved wisely for the future. The Government of the Northwest Territories has taken this opportunity to advance the preparation of a forward-looking Water Management Policy for the Northwest Territories. This policy is looking to the future in two ways:

1. It will prepare the Government of the Northwest Territories for the eventual transfer of provincial-type water management authority.

2. It will consider the implications and potential institutions as a result of the settlement of land claims.

The Government of the Northwest Territories Water Management Policy, now in draft form, will address such issues as:

- watershed planning units,
- water exports,
- diversions,
- industrial and municipal needs, and
- management for sustained populations of fish and wildlife.

The substance and intent of the Northwest Territories Water Policy has been influenced by territorial, national, and international economic and environmental policies and reports. This water policy will also form one of the pillars of a broader Northwest Territories Conservation Strategy now being developed. In particular, this policy is built upon the spirit and recommendations of the World Conservation Strategy, the Task Force on Northern Conservation and the Pearse Inquiry on Federal Water Policy.

In addition, this water policy is intended to demonstrate the application of the philosophy inherent in the report of World Commission on Environment and Development (WCED) and the legal principles for environmental protection adopted by that Commission.

When finalized, this policy will assist with the integration of land and water use planning. More importantly, the goals and principles outlined in the policy will serve as a guide for new water management initiatives. The Government of the Northwest Territories is fully aware of the challenge ahead of us. We plan to consult and work co-operatively with all agencies and groups in the Northwest Territories in order to fine tune and improve the policy.

TRANSBOUNDARY WATER MANAGEMENT AGREEMENTS AND PRINCIPLES

Like other aspects of northern existence, northern waters are influenced by events originating outside the Northwest Territories. Agricultural and industrial activities in southern Canada, the United States and elsewhere can, and do, adversely affect the North's water resources. For example, the majority of the water flowing through the western Northwest Territories originates in British Columbia, Alberta, Saskatchewan, and the Yukon Territory. The dam on the Peace River has already altered seasonal flows in the Northwest Territories and those proposed for the Slave and Liard Rivers will most certainly result in additional adverse effects.

Maintaining water quality and quantity standards which are acceptable to northerners is the major reason that the Northwest Territories is actively pursuing the establishment of Transboundary Water Management Agreements with our provincial neighbours. The intent of these agreements is to allow issues such as minimum flow, flow regulation and water quality to be addressed at jurisdictional boundary crossing points. We must recognize that water is a precious common resource and must be shared and managed wisely for present and future generations.

It is the intention of the Government of the Northwest Territories to negotiate bilateral agreements with each neighbouring province and territory. Once all the bilateral agreements are in place, it is hoped that a comprehensive umbrella water basin agreement could be reached for the Mackenzie River Basin. Previous Transboundary Water Management Agreements have taken up to twenty years to complete. However, we are confident that, by using this approach, comprehensive agreements can be reached much sooner. At this time negotiators from Alberta and the Northwest Territories are meeting regularly to define water uses and to establish an interim water quality monitoring program. Unfortunately, as these negotiations are ongoing, I am unable to discuss the specific terms of the agreements. Negotiations with other jurisdictions are also getting underway. Saskatchewan recently met with the Northwest Territories to initiate more formal discussions and Manitoba has sent correspondence indicating their interest in negotiations.

CLOSING STATEMENT

In closing, I would like to emphasize that we must take every opportunity now to ensure that our water resources are conserved for the future. We have an obligation to alter the present trends that are impacting on the quality and quantity of our water. In the Northwest Territories, there is growing recognition of the need for policies, legislation, programs and institutions that better reflect these emerging realities. We are searching for water management tools that are conducive to coping with challenges and opportunities in a flexible, forward-looking mannner. It is our responsibility now to put the tools such as Water Management Policies and Transboundary Agreements in place to ensure that our water resources will be protected for the benefit of all users, be they northern residents, tourists, industry or fish and wildlife.

DAMS AND DIVERSIONS:
LEARNING FROM CANADIAN EXPERIENCE

J.C. DAY[1] and FRANK QUINN[2]

ABSTRACT

The geography of Canada is such that water can almost everywhere be dammed and diverted readily between drainage basins. Engineers have responded, especially in recent hydroelectric megaprojects, to push interbasin diversion volumes well above those experienced in any other country. The pace has slowed, however, with rising construction costs, stabilizing energy demands and persistent interventions by natives and environmental critics. An exploration of politics, policies and public attitudes indicates reservations about this kind of development throughout the continent. Some lessons of a socioeconomic nature are ventured for consideration, in the event that major diversions are proposed to resume in the future.

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Even in a country with generous resources, economic activity begins sooner or later to press against natural limits. In the case of water in Canada, available resources vary considerably from one season or year to another and from one region to another. Engineers have managed to s-t-r-e-t-c-h surface water availability, however, by constructing dams which hold back runoff for release **when** it is most in demand, and by constructing diversions which redirect the resource to **where** it is most in demand. In fact, dams and diversions generally go together; water supplies are normally regulated in the basin of origin before they are withdrawn by ditch, canal, pipeline or other means for use in another drainage basin.

PRECEDENTS

Nature has provided an environment favourable for interbasin water diversion or transfer in Canada. More impressive even than the general abundance of fresh surface water is the density of interconnected and almost-connected lakes and rivers and streams which make up our drainage network. These are a legacy of the several advances and retreats of the Pleistocene ice fronts, before which meltwaters sought to escape by whatever routes possible, creating and abandoning drainage channels or simply spilling haphazardly from one shallow depression to another. Several thousands of years later, the resulting drainage pattern appears to be highly disorganized, especially on the Canadian Shield, as though "God had not sufficiently divided the land from the water there" (DeVoto, 1962).

Except for the western Cordillera, our basin divides are generally not formidable. Examples abound of lakes that drain in two directions and of rivers that overcome their divides in flood. The ease of portaging between different drainage systems was recognized early by natives and fur traders. Their prey and Canada's national symbol, the beaver, accomplished a certain level of stream damming and diverting on its own.

Where nature has shown the way, engineering has not been hesitant to follow, reopening Pleistocene spillways like that of the Great Lakes southward from Chicago to the Mississippi River and that of the South Saskatchewan River through the Qu'Appelle Valley. Other possibilities have not been realized -- Prime Minister Laurier lost the 1911 federal election before he could push the original St. Lawrence Seaway plan through the Georgian Bay - French River - Ottawa River route used by glacial meltwaters and voyageur canoes; the GRAND Canal is a latter-day revival of that dream. And Canadians generally would prefer not to see the Missouri River resume its former northerly course to Hudson Bay, if that means having to accept degraded water quality and the reunion of long-separated lifeforms via the Garrison Diversion Project.

In any event, Canadian water diversions have not had to resort either to long canals or pipelines or to high pumping lifts to the extent found in many European, American and Australian projects; we have advantages in short cuts between proximate water bodies and in gravity flows using largely natural channels.

PATTERNS

One of our more difficult tasks has been to establish criteria for qualifying diversions for purposes of an inventory. To require that diversions be interbasin poses the question of what basin boundaries to select, there being no set of basins in Canada which cannot be subdivided into smaller basins or combined into larger basins. Rather than struggle to distinguish between interbasin and intrabasin diversions, we adopted the following criteria:

(1) Diverted flow does not return to stream of origin (or parent stream) within 25 kilometres of point of withdrawal.

(2) Mean annual flow diverted is not less than a rate of 0.5 m^3/s.

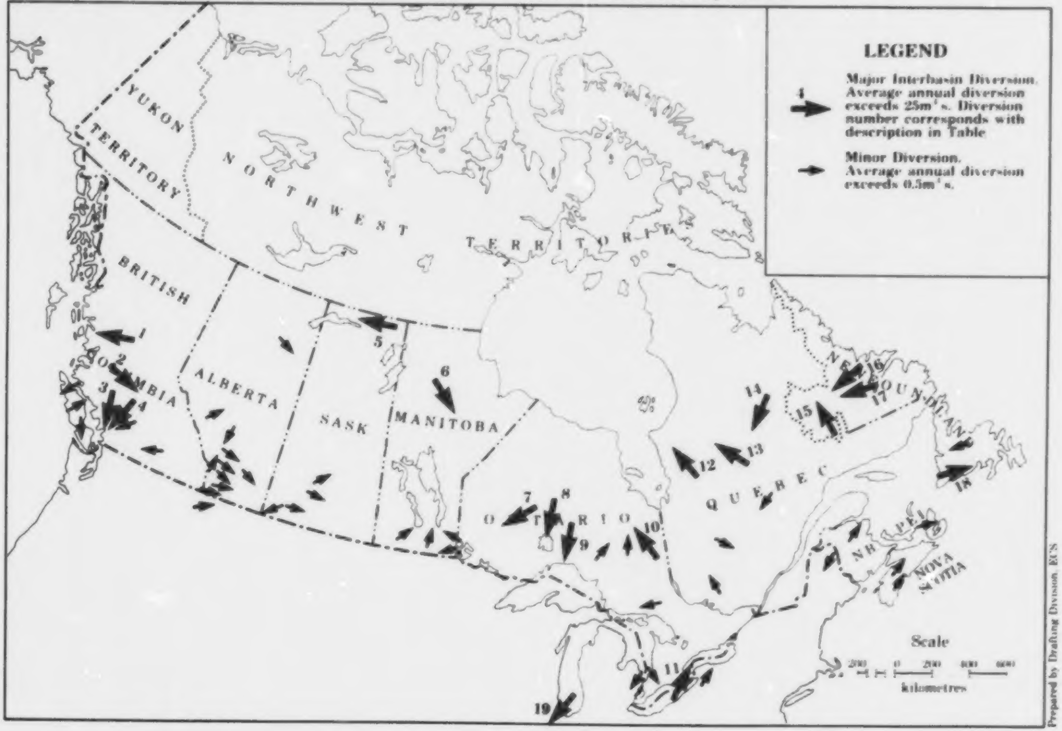
These have the effect of eliminating localized and smaller withdrawals operated by numerous municipalities, power plants and individual irrigators.

According to the criteria applied, 54 water diversions have been identified; these are scattered across nine provinces but have not reached either of the northern territories as yet (Fig. 1). The total flow involved in Canadian diversion -- 4,400 m^3/s -- is significant. If all of this flow were concentrated into a mythical new river, it would be Canada's third largest, behind only the St. Lawrence and Mackenzie Rivers.

During the past two decades, or roughly the period that the Environmental Movement was thought to have complicated the life of project builders, Canada has changed position relative to other nations from being a major diverter of water resources to being the largest diverter in the world. This has come about because of a very small number of very large recent diversions -- the Churchill Falls Project in Labrador, the Churchill-Nelson Diversion in Manitoba, and the La Grande River (James Bay Phase I) Project in Quebec (Table 1). The seven diversions included in these three projects account for two-thirds of all flow diverted in Canada.

Among the various uses, hydroelectric power dominates overwhelmingly in number and scale of diversions. Irrigation, flood control and municipal uses assume importance only regionally or locally. With approximately two-thirds of our electrical energy generated by falling water and 96 percent of our total water diversion attributable to hydro-electric projects, Canada is still very much hydro country. This is in marked contrast to the United States where, of the largest diversions reviewed (Petsch, 1985; Mooty and Jeffcoat, 1986), water supply for municipal and irrigation purposes dominates and hydro is hardly represented. In the American West hydropower is mostly a byproduct which helps to finance water projects intended to serve other purposes; in Canada, it is the main and usually only purpose of diversion projects.

Figure 1.
WATER DIVERSIONS IN AND AFFECTING CANADA, 1985


LEGEND
Major Interbasin Diversion. Average annual diversion exceeds 25m³/s. Diversion number corresponds with description in Table
Minor Diversion. Average annual diversion exceeds 0.5m³/s.
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND
NB
PEI
NOVA SCOTIA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Scale
200 0 200 400 600
kilometres

Prepared by Drafting Division, ECS

TABLE I

MAJOR WATER DIVERSIONS IN AND AFFECTING CANADA, 1985

No. Jurisdiction	Project	Contributing Basin(s)	Receiving Basin	Average Annual Diversion (m^3/s)	Uses	Operational Date	Owner
1 B.C.	Kemano	Nechako (Fraser)	Kemano	115	Hydro	1952	Alcan Ltd.
2 B.C.		Bridge	Seton Lake	92	Hydro	(1934)1959	B.C. Hydro
3 B.C.		Cheakamus	Squamish	37	Hydro	1957	B.C. Hydro
4 B.C.		Coquitam Lake	Buntzen Lake	28	Hydro	(1902)1912	B.C. Hydro
5 Sask.		Tazin Lake	Charlot (L.Athabasca)	25	Hydro	1958	Eldorado Nuclear
6 Man.	Churchill	Churchill (Southern Diversion	Rat.Burntwood (Nelson) Indian Lake)	775	Hydro	1976	Manitoba Hydro
7 Ont.		L. St.Joseph (Albany)	Root (Winnipeg)	86	Hydro	1957	Ontario Hydro
8 Ont.		Ogoki (Albany)	Lake Nipigon (Superior)	113	Hydro	1943	Ontario Hydro
9 Ont.		Long Lake (Albany)	Lake Superior	42	Hydro/ Logging	1939	Ontario Hydro
10 Ont.		Little Abitibi (Moose)	Abitibi (Moose)	40	Hydro	1963	Ontario Hydro
11 Ont.	Welland	Lake Erie Canal	Lake Ontario	250	Hydro/ Navig.	(1829)1951	Govt. of Canada
12 Que.	James Bay	Eastmain-Opinaca	La Grande	845	Hydro	1980	J.B. Energy Corp.
13 Que.	James Bay	Frégate	La Grande	31	Hydro	1982	J.B. Energy Corp.
14 Que.	James Bay	Caniapiscau	La Grande	790	Hydro	1983	J.B. Energy Corp.
15 Nfld.	Churchill/ Falls	Julian-Unknown	Churchill	196	Hydro	1971	Nfld. & Lab. Hydro
16 Nfld	Churchill/ Falls	Naskaupi	Churchill	200	Hydro	1971	Nfld. & Lab. Hydro
17 Nfld.	Churchill/ Falls	Kanairktok	Churchill	130	Hydro	1971	Nfld. & Lab. Hydro
18 Nfld.	Bay d'Espoir	Victoria, White Bear, Grey and Salmon	Northwest Brook (Bay d'Espoir)	185	Hydro	1969	Nfld. & Lab. Hydro
19 Il.	Chicago	Lake Michigan	Illinois (Mississippi)	90	Municipal/ Sanitation	(1848)1900	Chicago San. Dist.

Publicly-owned provincial power commissions are responsible for most of Canada's largest projects. Their principal objective has been to maximize low-cost power generation and thus to move electricity, not water, to growing population centres. Canada's water diversion map, for that reason, does not have an orientation from north to south, from wetter to drier regions, from less-populated to more populated basins. The pattern is unlike that of any other country.

PROSPECTS

There is growing doubt whether the pace of construction of interbasin diversion projects in Canada is likely to continue. Most of our large diversions serve hydroelectric purposes. At present, Canada has surplus hydro generating capacity, having overbuilt major projects in Quebec, Manitoba and British Columbia in the mid 70s - to - mid 80s decade when rising world energy prices and economic recession led to a dramatic fall-off from the expected growth of energy demand. Proposed free trade in a continental energy market may take up the slack in demand, but in the near future there is ample potential for further hydro development in Canada on rivers which are already regulated -- Site C on the Peace, Conawapa on the Nelson, LG1 on the La Grande, Muskrat Falls and Lower Churchill in Labrador, among others -- without looking to new diversions. Of all the provinces, only Quebec, with an eye on further electricity exports from James Bay, appears anxious to initiate more interbasin diversions before the turn of the century.

What about major water diversion from our northern rivers for other purposes than generating hydroelectric energy? Some people have visions about expanding irrigation on the Prairies, controlling the levels of the Great Lakes, exporting to the United States. But proceeding to this more ambitious level of diversions will not come easily, as reference to developments south of the border should make clear.

With the completion of existing commitments, such as a scaled-down Garrison Project, the era of damming and diverting waterways is drawing to a close in the United States. The best dam sites have been developed, water sources nearest to growth centres have already been fully appropriated, and investigations of major interbasin diversion possibilities have been stopped cold, both by the political resistance of better-watered states to sharing their advantage and by the withdrawal of traditional federal project subsidies in the face of mounting budgetary deficits. It is thus cheaper to conserve and to reallocate local water supplies than to develop distant sources. Whatever is left of the federal construction program will proceed only to the extent that state and local interests are willing to share substantially in the costs (Mosher, 1987). Project-building agencies therefore are struggling to adapt to a new era of conservation of water quantity and reclamation of water quality, which in many cases amounts to correcting past excesses and inefficiencies.

Interestingly, the words **water transfer** now have quite different meanings on either side of the 49th parallel. Canadians still understand the process to be a physical displacement of flow for use in another channel or drainage basin, whereas in the American West it has come to mean the sale or lease of water rights from one user to another, usually from agricultural to municipal or industrial users. In this respect, lawyers and realtors marketing established rights among users seem to be taking American water management in a different direction than the engineers who preceded them.

In Canada, of course, the engineering fraternity still controls the water establishment. This is the fraternity which, when Canadians overwhelmingly rejected the first water export schemes in the 1960's, took it as a signal to substitute diversions inside the country for those aimed south of the border. Thus, there quickly followed in 1965 Alberta's PRIME north-south diversions plan and the Canada-Ontario investigations of James Bay drainage, including potential for diversion into the Great Lakes. (Quebec declined to join these governments and carried on its own studies in this region until it was ready to announce its own James Bay Program in 1971.) In 1966 Canada and Manitoba reached agreement on the Nelson River Program that encouraged the province to proceed with the Churchill Diversion. In 1967 Canada, Alberta, Saskatchewan and Manitoba began investigations of various combinations of dams and diversions which could supplement available water supply in the Saskatchewan - Nelson basin. In all cases social and environmental concerns were set aside, at least until the basic hydrologic and engineering potential could be established.

This fixation on physical potential, combined with a history of planning behind closed doors, has served to reinforce public suspicions about governments, and their hydro commissions in particular, whenever future water needs are at issue.

POLITICS

According to the Constitution Act, the provincial governments have proprietary rights as owners of the resources found within their borders, as well as legislative authority over most kinds of water development. Thus, provinces legislate extensively in matters of domestic and industrial water supply, irrigation, electrical power, recreation, flooding and pollution control. Since virtually all interbasin diversions in Canada have been implemented within provincial boundaries for one or another of these purposes, they are governed mainly by provincial laws and institutions. Indeed, these institutions, especially the hydroelectric commissions and irrigation districts to which so much provincial administrative responsibility has been delegated, own and operate directly a great many of Canada's water storage and diversion facilities. The resources amendment to the Constitution Act in 1982, Section 92 A, confirms provincial control of hydroelectric power facilities as well as nonrenewable resources.

The federal government also has jurisdiction over some matters affecting water resources which can be brought to bear on diversion projects and proposals. Federal jurisdiction is complete in the northern territories and in the marine environment offshore, but these huge areas are little affected by diversions to date. Federal proprietary rights also extend to national parks and Indian reserves south of 60°N, and these have occasionally suffered impacts from provincially-regulated diversions. In addition, the federal government has exclusive legislative authority over fisheries and navigation, and certain power over extraprovincial undertakings, and in the conduct of foreign relations, including trade and commerce and treaty-making, the latter having great significance for developments affecting Canada - United States boundary waters (Rueggeberg and Thompson, 1984).

Attempts to sort out provincial and federal legislative jurisdictions over a fugitive resource which straddles and crosses political boundaries and which lends itself to so many different uses remain a formidable challenge. Ambiguities abound, court decisions are few, and governments often prefer to negotiate cooperative arrangements with one another rather than test the limits of their power to act unilaterally. Indeed, one observer has gone so far as to make a distinction between Canada's legal constitution and its "political constitution"; on sensitive matters, the federal government may be reluctant to press its position against strong opposition from the provinces (Lucas, 1986). As a consequence, federal involvement with interbasin diversion projects develops typically "through the back door". The pattern is for the provinces to act and for the federal government to react, often belatedly. Collaboration between British Columbia and Alcan for hydro-related diversion at Kemano in the 1950s precipitated serious federal fisheries objections and a new agreement on co-existing uses only in the 1980s. Decisions were made by Manitoba to divert the Churchill River and by Quebec to divert the La Grande River, in both cases with indifference to native interests, until Ottawa supported the latter in legal proceedings to win fair settlements for loss of territory and livelihood.

If only a minority of interbasin diversions have attracted federal intervention to date, these cases nevertheless indicate a trend toward more such involvement in the future, brought on not by a change of political philosophy but by increasing project scale, by impacts on more interests and jurisdictions, and by growing public perception of the federal government as the "court of last resort". Certainly, water export proposals of any kind are subject to federal as well as provincial jurisdiction, and public opinion expects leadership from the federal government on this controversial issue.

In the end, of course, politics in Canada must be seen as more than federal-provincial relations. For one thing, the general public is not interested in all the niceties of jurisdictional separation in the face of real issues demanding attention. For another, we would suggest that interbasin diversions are held in the same low regard by many observers as water export proposals because they are both perceived as colonial practices used by centres of political power to exploit the hinterland and its scattered inhabitants.

POLICIES

There are no (headwaters) area-of-origin or basin-of-origin statutes in Canada, nothing comparable to the protection written into some state laws and interstate compacts south of the border, assuring such areas adequate water for future needs, rights of recapture, priority for certain uses or financial assistance for local projects, in return for release of their "surplus" waters (Quinn, 1973). We have gone part way in that direction, however, in settlements negotiated between native communities and provincial hydro commissions over diversion project impacts, even if these take the form of compensation for flooding and contamination rather than for loss of the resource itself.

Interjurisdictional agreements have been exercised as a means of sharing benefits of, or removing barriers to, diversions involving transboundary rivers. Ontario reimburses Quebec in proportion to the benefits received at Ontario Hydro generating plants on the Ottawa River from diversion of the Gatineau into the upper Ottawa and storage at Dozois; Manitoba similarly reimburses Ontario for the latter's storage and diversion of flow from the Albany River to the Winnipeg River. Conversely, negotiations between Canada and the United States to apportion rivers crossing the Alberta-Montana boundary removed uncertainties about external obligations and left each country free to proceed with separate diversions -- the Waterton-Belly-St. Mary Project north of the border and the St. Mary-Milk Project south of the border. Similar results have not yet followed the Prairie Provinces Water Apportionment Agreement of 1969, and may or may not follow the ongoing negotiations among federal, provincial and territorial governments concerning apportionment of transboundary tributaries of the huge Mackenzie Basin.

Within each jurisdiction, basin residents and water users exercise influence, often out of proportion to their numbers when resisting extrabasin pressures to share their waters. Their rallying cry, to respect the integrity of the river basin, has enjoyed a rennaissance in water planning circles. This is especially the case in Alberta where the province has scrapped its PRIME diversion scheme and promulgated among its water management principles (Alberta Environment, 1979) one which declares:

> "The waters in each major basin must be fully and efficiently utilized before interbasin augmentation could be considered."

In refusing to participate in this symposium, Alberta Environment officials are presumably telling us something about the opportunities for greater efficiency to which their water users can look forward.

The newly-released federal water policy (Environment anada, 1987) addresses the issue of interbasin diversions in both its international and domestic dimensions. In the strongest terms it has used since the first water export proposals were dismissed a quarter century ago, the Government of Canada underlines that it will:

> "...take all possible measures within the limits of its constitutional authority to prohibit the export of Canadian water by interbasin diversion; and strengthen federal legislation to the extent necessary to fully implement this policy."

The exception to this prohibition applies to water export in small volumes by tanker ship, a practice which will be regulated in collaboration with coastal provinces.

In the matter of interbasin diversions within Canada, the federal water policy adopts the cautious approach recommended by the Pearse Inquiry (1985), not opposing the practice outright but discouraging its use except as a last resort:

> "The federal government advocates exercising caution in considering the need for major interbasin transfers and endorses other less disruptive alternatives such as demand management and water conservation to satisfy societal needs without sacrificing water related values to irreversible actions."

In support of this position, the federal government will proceed to:

> "draft guidelines and criteria for assessing interbasin transfers within Canada in cooperation with the provinces/territories."

There is a connection between domestic interbasin diversion and diversion for export to the United States which should not be missed. The draft Canada-U.S. free trade agreement gives no explicit exemption to water among the natural resources to which trade barriers will disappear. International (GATT) rules, however, allow nations to restrict exports on conservation/environmental protection grounds, and it is on this basis that the federal water policy prohibits major water export. Canada's case would not be very convincing if we were to promote the large-scale diversion of water within the country that we were prohibiting for export purposes.

This resolution of positions on diversions internally and externally will probably not be acceptable to Quebec, where new diversions are being planned as part of its continuing James Bay hydro program. A further wrinkle here is whether there is any fundamental difference between committing water to export and building projects for the generation of electricity which is then committed to export.

PRESCRIPTIONS

We have had the opportunity to review the effects, good and bad, of several major Canadian interbasin diversion projects over the past decade (Day, 1985). Even though Canadians move more water by volume across basin divides than any other people on earth, it is apparent that we are not yet able to anticipate the full range of consequences of our actions. This is because we have become more proficient as project builders than as students of their effects and consequences. Our engineering technology for controlling and redistributing the flow of mighty rivers has been good enough to apply around the world, but almost everything else has been relegated to afterthought status: market forecasting, community relations, interagency and intergovernmental coordination, and environmental monitoring and assessment.

We make some suggestions below for improving the process of selecting, building and operating interbasin diversion projects in the future. Our remarks are limited to the socio-economic sphere, in the expectation that most of the participants at this symposium will focus their attention on the biophysical environment. Some of our remarks apply to big hydroelectric projects, with or without interbasin diversions; the latter, however, have the potential to contribute impacts of a larger order of magnitude and of a different kind (for example, biota transfer).

Alternatives

New dam and diversion projects should not be approved until all alternatives have been thoroughly explored. This should include demand management alternatives such as pricing and conservation options for diversion-derived water and electricity, as encouraged in the new federal water policy. Such an approach would help eliminate or at least defer the need for the massive environmental and social disturbance and public debt associated with megaproject diversions as long as possible. The importance of considering alternatives, both means and ends, cannot be emphasized too strongly.

Project Economics

The forecasts of project costs, benefits, and markets for energy, crops or other outputs have often been overly optimistic. Normally, project costs are much higher and benefits much lower than originally anticipated. This has raised the diversion-related debt level of hydroelectric utilities in some provinces to undesirably high levels.

Increasingly, diversions have been used as a means of promoting short-run economic activity and job creation to alleviate sluggish economic conditions. In this sense, the potential to transfer water may be considered an expendable resource which may be used only once for the purpose of economic stimulation. Indeed, very little long-term employment is created by such projects. As a result, great care must be taken to ensure that the long-term economic consequences of such projects do not impose an excessive debt load on future generations. Society will benefit from well designed projects or pay for negative developments caused by currency fluctuations, interest rate changes, loss of markets, unforeseen biophysical impacts, or native claims for land ownership or compensation, all of which can work against project profitability in the long term.

Projects should only be built when firm, long-term contracts for their output are in hand. For example, the recent Manitoba approach to planning and constructing the Limestone project associated with the Churchill-Nelson diversion was based on this principle and is a promising model for other provinces to consider.

If security is important, so is contract flexibility. Flexible energy sales agreements are desirable so that the value of energy sales is automatically adjusted annually as key economic variables change. Long-term, fixed-price, electricity export contracts such as those negotiated for the Columbia River Treaty or for the agreement between Newfoundland and Quebec have proven disastrous for generating provinces and should never be repeated in future arrangements.

Intergovernmental and Interagency Coordination

Provincial governments have at times moved too quickly to approve complex water developments. As a result, various federal and provincial agencies with responsibilities for managing fisheries, parks, wildlife, Indian affairs and other affected interests have insufficient time to react and to ensure that these interests will not be disadvantaged. Resultant costs to mitigate or compensate effects of provincial water projects are too often transferred to federal taxpayers.

Another problem arises when agencies responsible for building certain kinds of resource projects also are in the position of judging the need for these projects. This kind of bias by B.C. Hydro toward its Site C hydro project was blocked only because the province had established an independent commission in charge of all energy matters province-wide and that commission (B.C. Utilities Commission, 1983) found against the need for this $3.2 billion project after extensive public hearings. This kind of independent authority is particularly valuable in establishing long-term demands and alternative strategies before proponent agencies proceed with detailed project planning.

Community Relations

Those to be affected by major diversions have seldom been adequately consulted before the decision to proceed has been taken, nor told, except in the most general terms, what will happen to them and when, by project planners. Such a decision making approach greatly exacerbates the community confusion, social unrest, and disturbance induced by such enormous undertakings.

An operations committee, composed of all major interest groups whose concerns are to be affected in the project basins, could be a useful advisor before diversions are selected to operate. This would ensure that all needs in a project area are known before new water flow patterns begin and that as many local flow requirements are met as possible. In general, diversion should be managed to incorporate other purposes, at least to reasonable limits.

Special attention needs to be directed to mitigating the impact of diversions on local residents. To do so, a long lead time is necessary for education, negotiation, planning, and compromise. Agreements and monitoring systems should be in place before construction begins so that problems which emerge during construction and operation can be mitigated or compensated within a reasonable period. Those in charge of project implementation must report regularly to the responsible ministers on progress and problems to ensure that problems are corrected immediately. Conflict resolution mechanisms are also necessary for those times when an impasse is reached between the project proponent and local residents whose welfare is threatened by a diversion. Affirmative action programs are essential if those negatively affected by such projects are to share in the local economic opportunities created during the construction and operation periods.

In general, these measures have not been built into most diversions. They are easily achieved, however, give the political will to do so.

Excellent models which incorporate all of the innovations described above are now available from recent experiences with the James Bay project in Quebec and the Limestone project in Manitoba. Both of these examples are worthy of careful study.

Special attention is required to comprehend the effects of diversions on the pace and direction of social change in native communities. Large diversion-related transfer and compensation payments, particularly in northern Quebec, have induced rapid urbanization and population growth in Cree communities. However, the long-term ecological and economic sustainability of the economy of large native settlements such as Chisasibi, which are based largely on transfer payments, is unknown. In this instance, approximately half of the community, which is expected to reach 4,000 by the mid-1990s, is employed full-time in hunting, fishing, and trapping. Research is needed to determine if small dispersed settlements, which are characteristic of traditional native communities, would be more ecologically sustainable, economically viable, and socially acceptable to native parties affected by diversions.

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PLENARY SESSION

PERSPECTIVES ON THE GRAND CANAL

Moderator: Mr. D. Richards

Saskatchewan Water Corporation
Moose Jaw, Saskatchewan

RECYCLED WATER FROM THE NORTH

THE ALTERNATIVE TO INTERBASIN DIVERSIONS

TOM KIERANS, P. Eng.
Author of the GRAND Canal Concept

ABSTRACT

In Canada's short history and throughout the world for centuries before, interbasin transfers of fresh water have been essential in resolving regional water supply problems. Expanding populations will need more transfers to maintain and improve living conditions, protect environments and assist the production of food, energy, goods and transport.

However, traditional water transfers by gravity-flow "diversions" even in remote areas, have become unpopular in Canada and elsewhere. This is due to public concern with; downstream water losses in the donor basin, associated ecology changes, and winner/loser conflicts between basins. Nevertheless, to resolve current and future regional water supply problems, an acceptable and practical transfer system is needed.

"Recycling" is proposed as an alternative to diversion-type transfers. This involves the pumping of fresh water runoff from tidal basin enclosures. Its two basic components have been proven in operation in the Netherlands and in California for many years. While some water authorities, possible because of a long and exclusive association with diversions, still fail to see the difference; recycling contrasts sharply with diversions. It is a unique conservation measure which increases fresh water resources in both the donor and receptor basins. It avoids "water export" losses. Recycling improves control of water levels. Many of the environmental problems of diversions are avoided. All participants appear to be winners.

The GRAND Canal concept proposes to recycle fresh water runoff from a new James Bay tidal basin enclosure. The Concept offers Canada an excellent opportunity to profitably resolve national and shared water supply management problems with the United States. It will substantially increase Canada's water resources and flows and develop the North.

Many Canadians now accept the potential advantages of recycling and support proposed studies. Those water authorities who still believe gravity-flow diversions are the only way to transfer water, prejudice the needed recycling studies. Because of a failure to recognize the differences they include recycling in their opposition to diversion transfers. Thus, major Great Lakes and midwest water supply problems, only correctable by recycling fresh water from James Bay, are unresolved. A promising opportunity to develop Canada's north in the long term interests of native people and Canadians in general is deferred. Design criteria to ensure protection of all Canadian interests are included in this submission.

Recent federal reports indicate that distinctions between water recycling in contrast to diversions are not understood at this time. The purpose of this paper is to clarify the differences. The GRAND Canal Concept is the only recycling concept that has been proposed in Canada up to this time. All other proposals for water transfers have called for diversions.

INTRODUCTION

To usefully discuss questions of interbasin transfers of fresh water in Canada, it is first necessary to refer to the following facts:-

Supply and Distribution

1. On the basis of average annual per capita water flow or runnoff, Canada is clearly the richest nation in the world, with 110 thousand cubic meters per person, compared to 10 thousand cubic meters in the U.S.A. and the world's declining average of 8.3 thousand cubic meters per person. (World Watch Institute Bulletin #62).

2. In spite of Canada's overall abundance, the natural distribution of water flow across the nation is very uneven.

3. To resolve regional water supply problems of deficiency or excess and to equalize, as far as possible, economic growth opportunities across the nation, managed interbasin transfers are essential.

Diversions vs. Recycling

4. There are two basic systems for achieving interbasin transfers:-

   (a) The traditional method is gravity flow diversion of the headwaters of donor river basins. Such diversions are becoming increasingly unpopular because of downstream flow losses with ecological and social impacts and winner/loser conflicts between the basins involved;

   (b) The more recently developed method is recycling fresh water for reuse elsewhere by pumping from sea level tidal basin enclosures or river deltas. This method is, in the short term, more costly to implement and operate but, in the long term, is more productive, both environmentally and economically. In contrast to diversions, water recycling creates **new fresh water resources that did not exist before. It avoids winner/loser water conflicts.**

   Such recycling presents an attractive opportunity for Canadians to profitably resolve difficult water supply problems with the U.S.A., and at the same time increase Canada's own water resources.

5. Early in this century, the creation of new, fresh water resources, in large, tidal basin enclosures, was successfully pioneered with the establishment of the fresh water IJselmeeer in the Netherlands' former Zuider Zee. About the same time, California started to recycle water, for reuse elsewhere in the State, by pumping fresh water from the Sacramento River's delta -- just before it would normally be lost to the sea. The State has now profitably extended its water reuse and recycling system for over seven hundred kilometers.

Problems and Opportunities

6. Critical problems now needing major interbasin transfers are:

   (a) widening level fluctuations in the troubled, international Great Lakes - St. Lawrence Basin which Canada shares with the United States.

   (b) worsening water deficiencies in the dry, mid-west where important river flows cross the international boundary.

   Effective long term resolution of Greak Lakes stabilization problems will call for very large and fully controlled inflows during low water periods. During high water there is a need to remove large volumes from the Lakes and to have a location, such as the Canadian and U.S. mid-west, to which the new outflows can be beneficially discharged. The proposed James Bay tidal basin enclosure is the only potential source for the large volumes of water needed to dependably supply fresh water to both the Great Lakes and the mid-west on a continuing basis.

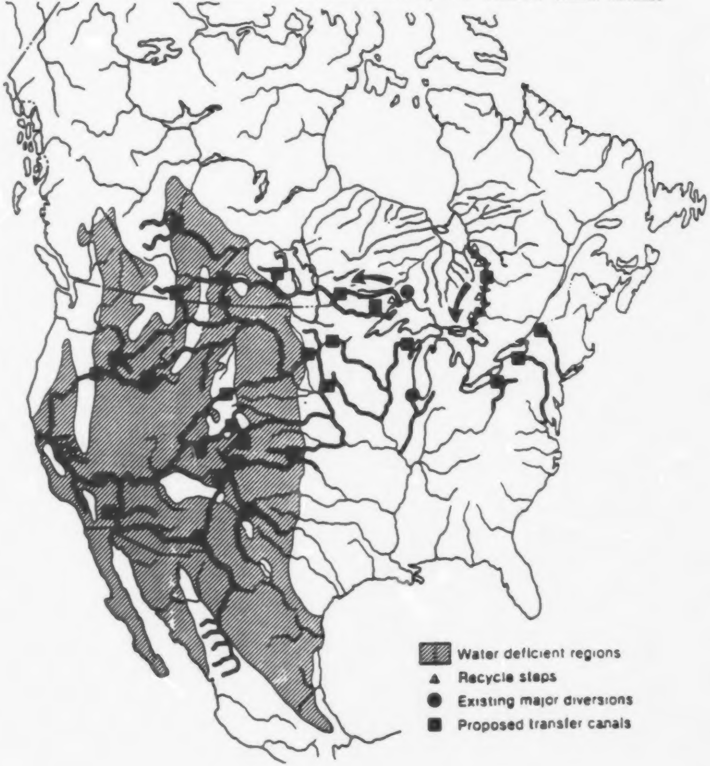
   There is a need to protect the James Bay Basin against proposed southward diversion of the headwaters of its north flowing rivers. There is also a need to benefit that region by the protective and profitable development of its most valuable natural resource, namely fresh water, through a tidal basin enclosure in James Bay.

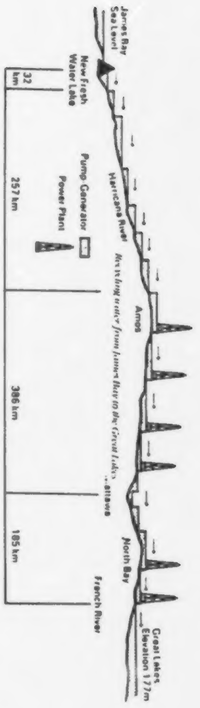
The GRAND Canal Concept

7. The Great Recycling and Northern Development (GRAND) Canal Concept (Figure 1) proposes to change much of shallow James Bay into a productive, fresh water lake. Some of the large volume of basin runoff, preserved by dikes from tidal-mixing, will be recycled, as needed, to stabilize Great Lakes levels. Concurrently, the mid-west will receive fresh water from the Lake's new controlled inflow/outflow system. Major water problems, which Canada must share with the United States, will be profitably relieved. James Bay will be protectively developed and Canada will have much more, not less, fresh water than it has now.

8. The several recent reports on federal water policy indicate that the contrasting differences between recycling and diversions are neither understood nor recognized by those responsible for the reports.

Figure 1. Great Recycling And Northern Development (GRAND) Canal Scheme


Water deficient regions
Recycle steps
Existing major diversions
Proposed transfer canals


James Bay
Sea Level
New Fresh
Water Lake
Pump Generator
Power Plant
Harricana River
Amos
Recycling water from James Bay to the Great Lakes
...attawa
North Bay
French River
Great Lakes
Elevation 177m
32 km
257 km
386 km
185 km

WATER IN CANADA

When Canada became a nation 120 years ago, the world's population was a little more than one billion people. Now there are five billion. Before the next century begins - thirteen years from now - there may well be six billion. Canadians, with only one half of one percent of the world's population and seven percent of its landmass are blessed with about nine percent, or $100,000 m^3$/sec, of the world's total renewable runoff. The World Watch Institute has reported that, in 1983, on an annual per capita basis, Canada ranked first in the world with runoff equal to $110,000 m^3$ per person per year. This contrasts with only $10,000 m^3$ per person in the United States. China had $2800 m^3$. Egypt had only $900 m^3$. The average annual per capita runoff in the world was about $8300 m^3$. By the year 2000, the world's per capita runoff will be only $6300 m^3$ per person per year. Due to increasing world populations the decreasing average annual per capita volume of fresh water will impact on living standards in all nations. Canadians, with their very high, but unevenly distributed, natural allotment of fresh water, will come under increasing geopolitical pressures, both inside and from outside the nation.

Water Distribution

While Canada is abundantly endowed with fresh water, it is not evenly distributed across the nation's ten provinces and two territories. Average annual precipitation varies from more than 250 cm on the Pacific Coast to less than 35 cm in southwest Saskatchewan. In the international Great Lakes Basin, there are long periods of extremely high water levels which can be followed by similar periods of very low water. The trend in this basin is predicted to be towards lower average levels and flows.

Water Issues

As world populations increase and the per capita demand for the fixed supply of natural fresh water becomes more critical, water supplies within a watershed jurisdiction will hold a rising level of social and economic importance over all other considerations. The present trend toward isolation of watersheds in dealing with regional water supply problems is based on the following:

- concern with environmental changes that may result from water diversion type transfers,
- concern with potential antagonisms between residents of donor and receptor river basins;
- the fear of losing or reducing existing natural water supplies.
- mistrust of comprehensive interbasin management systems because of their potential complexity;
- regionalism or nationalism with a preference for non-involvement with neighbours in problem solving;
- cost/benefit concerns; and
- lack of awareness of recycling as an alternative to diversions.

Canada's Major Water Problems

The following is a very brief summary of Canada's major water supply problems. The troubled international Great Lakes suffer widening level fluctuations. A main cause is the combination of very large surface areas in the Upper Lakes and limited flow capacity between Lakes. Several years of higher or lower than average precipitation, results in levels which are respectively very high or very low. High levels cause heavy erosion. Low levels reduce water quality and impair shipping and hydropower production. The fact that the Lakes are shared with the U.S. complicates management for Canada.

The second major water problem is in the mid-west. In this region, both in Canada the U.S.A., average annual precipitation is chronically low. It is forecast to worsen; darkening the future for many millions of people. Watershed boundaries cross the international border in several areas.

A third, wholly Canadian, factor is the water rich, sparsely populated and underdeveloped James Bay Basin. This is the only watershed which could provide a dependable source for the large volumes of fresh water needed to solve the first two problems. In the early 1940's, the southward diversions of the headwaters of north flowing rivers created the concerns which have led to the present opposition to further diversion-type transfers in Canada. An acceptable alternative to diversions is urgently needed now. The Great Recycling and Northern Development (GRAND) Canal Concept offers such an alternative, - for objective study.

Water Policy Options

Two basic directions for policy development in Canada are emerging:

- Unitized basin management policies:

  These endorse the isolation of major watershed units. Natural water supply controls the resolution of local or regional water problems. Resource and economic development is limited to natural supply. Major interbasin transfers are rejected.

- Cooperative interbasin management policies:

  These emphasize the interdependence of all of the nation's water resources and water needs. Cooperative transfer systems are encouraged to resolve regional supply problems.

The success of this second policy approach depends to a large extent upon the potential to create a new fresh water resource by recycling from a large tidal basin enclosure. This avoids winner/loser problems. The James Bay tidal basin offers such a potential new water resource.

The Present Direction of Canadian Water Policy

Unfortunately, the present trend in Canada and U.S.A. is to unitize watershed management. This is confirmed by:

- The Great Lakes Charter, signed in 1984, by the two Canadian provinces and the eight states occupying the Great Lakes - St. Lawrence Basin. The Charter severely restricts and restrains new withdrawals from the Great Lakes, even under the recent extreme high water conditions;
- the 1984-85 Inquiry on Federal Water Policy, which was generally negative to interbasin transfers.
- the statement of the federal Minister of the Environment on April 6, 1986, expressing his opposition to interbasin water transfers, even to serve solely Canadian needs.
- the negative preoccupation by Canada's Interdepartmental Water Policy Task Force in its 1987 Report with so-called "water exports". The report failed to recognize recycling as an alternative to diversions and misleadingly implies that such "exports" would reduce existing water resources in Canada.
- the reluctance of the International Joint Commission to seriously consider major inflows and outflows as a solution to Great Lakes level stabilization problems.

The unfortunate result of the trend to unitized watershed management will be the continuation of the present widening range of Great Lakes levels fluctuations. Relief of chronic water deficiencies in the mid-west will be obstructed. Canada's water-rich James Bay Basin will remain underdeveloped.

The Recycling Alternative to Diversions - The GRAND Canal

The Great Recycling and Northern Development (GRAND) Canal Concept proposes that internationally shared water management problems in the Great Lakes and the Canadian and U.S. mid-west be resolved concurrently and cooperatively with the development of recycling technology in the water-rich James Bay Basin.

A large, new, dike-enclosed, very high flow-through, fresh water lake, similar in design to the Netherland's lake IJselmeer, will be created in shallow James Bay. Some of this new, fresh water will be recycled, as needed, to the Great Lakes and to the mid-west.

The fresh water inflow into James Bay is 9000 m^3/sec or almost twice the flow of all the Great Lakes combined. Some of this huge volume of fresh water from the new lake, will be recycled, as needed, to provide a large new, controllable inflow into the Great Lakes. At the same time, a new outflow system from the Great Lakes will be designed to transfer dependable large volumes of water to the areas of water deficiency in the

Canadian and U.S. mid-west. Because Canada shares the international Great Lakes Basin with the United States, it will be essential to have U.S. concurrence in resolving level fluctuation problems in the Lakes by means of recycled water.

In delivering water from the Great Lakes to the Canadian and U.S. Prairies, there are advantages for Canada in selecting a Canadian route for the new water. A potential routing through Canada would deliver water from Lake Superior in Ontario to Lake Diefenbaker in Saskatchewan. Such a route would be via Lake Nipigon, Lake St. Joseph on the Albany River, and the Winnipeg, Red, Assiniboine and Qu'Appelle River basins. A study by the Canada West Foundation has already called the western part of this system the Qu'Appelle River Conveyance Channel.

Recycling, from this new source of fresh water, avoids winner/loser conflicts and reasonable objections to "water export". The proposed new Canadian water source does not now exist as fresh water. When the Concept is implemented, Canada will have much more, not less, fresh water than it has now. It will be created for, and could only be used for, the specific purpose of resolving international water problems which Canada must share with the U. S. in the Great Lakes and the mid-west. Design criteria will protect all Canadian interests before agreement on final design is concluded.

The proposed, fully controlled, recycling system will call for pumping stations, reservoirs, open aqueducts, power plants and flow control structures. Designs will conform with natural river basins to improve existing flood control measures. Pumping energy needs will be balanced with down-flow energy recovery and net surpluses or deficits coordinated with existing power utility grids.

Objective studies may show that possible, unwanted, environmental side effects from the proposed recycling system are benefits. Over 150 million people in Canada and the U.S. will be served by the GRAND Canal. Thus, per capita costs will be modest and far less than failing to solve the problems. Revenues will flow, as in California, from improved economic productivity; - not higher tax rates. The proposed Canadian investor-owned utility will be publicly regulated. It is expected that major investors will include provincially owned energy producers.

Basic Components

Essentially the Concept can be divided into five major components as follows:

A) The new fresh water lake in James Bay with its enclosing dikes and level control system;

B) The transfer system from James Bay to the international Great Lakes including the intake system, special aqueducts, reservoirs, pumping plants, energy supply systems and inflow and outflow controls;

C) The Great Lakes new inflow/outflow stabilization control system;

D) The outlflow system from the Great Lakes to water deficient areas in Canada including intermediate reservoirs, aqueducts, related pumping plants, energy supply requirements and distribution systems;

E) The outflow system from the Great Lakes to water deficient areas in the United States including intermediate reservoirs, aqueducts, related pumping plants, energy supply requirements and distribution systems.

Design Criteria for Recycled Water from the North

In order to critically examine water management proposals regarding Canada's three major water problems, rigorous design criteria are needed. They should include practical political, economic and environmental realities. The following is a preliminary list of some basic criteria for recycling proposals involving level instability on the Great Lakes, water deficiency in the mid-west and the development of northern water resources by recycling from tidal basin enclosures.

1. An acceptable proposal should be able to create enough new fresh water at sea-level to concurrently and effectively resolve Canada's three major problems of Great Lakes level stabilization, mid-western water deficiency and northern water resource development.

2. Effective mitigation should be provided for possible undesirable side-effects resulting from a proposed new, sea-level, dike-enclosed lake or transfer and control system.

3. Acceptable proposals should not create antagonisms between donor and receptor watersheds.

4. Acceptable proposals must not reduce Canada's natural water resources either in volume or in flow as a result of any transfers between Canada and the United States. In this regard, transfers to the U.S. mid-west should, as far as possible, be carried out after all potential transfer routes and needs in Canada have been utilized.

5. Capital, maintenance and operating cost of the system should be repaid, under contract, by bereficiary jurisdictions and covered by increases in national and regional economic productivity. Cost repayment schedules should be based on realistic calculations of anticipated increases in GNP and not on increases in tax rates or inordinate user fees.

6. An acceptable concept must be able to safely control flooding and prevent contamination of water for public use by wastes or toxic chemicals throughout the entire system.

7. There must be acceptable benefits for native and other residents in all of the jurisdictions involved.

8. Components of the recycling system within a given region should be regulated by the jurisdictional authorities within that region.

9. Acceptable concepts should, as far as possible, be designed for stepped development and expansion as needed or alternatively for a sufficient number of benificaries so that per capita costs are acceptable in comparison with benefits.

10. The pumping power system for upflows should, as far as possible, use non-acid rain producing energy. Gravity flow components of the system should be designed to recover as much hydropower energy as possible.

The proposed Great Recycling and Northern Development (GRAND) Canal Concept has been designed to conform to the above preliminary criteria.

Research and Studies into the GRAND Canal

A proposed outline of Concept studies and research into the GRAND Canal Concept for "Recycled Water From the North" is under preparation. With the assistance of the National Research Council of Canada, some of the items in the proposed program have already been investigated on a preliminary basis. The following is a preliminary outline of some of the items which will finally be included in the proposed studies:

- Institutional Frameworks for Studies
- Study Preparation
- Alternative Routing and Preliminary Costs and Evaluation
- Environmental Assessment Programs
- Regional Needs
- Energy Systems Balance
- Precedents Worldwide
- Biotransfers
- Estuarial and Deep Sea Effects
- Environmental Disbenefits and Mitigation Proposals
- Environmental Benefits
- Social Considerations
- Demographic Distribution
- New Employment Opportunities
- Community Development
- Effects on Transportation
- Effects on Communication
- Social Services
- GNP Input/Output Studies
- Final Design Criteria
- Project Implementation Schedule
- Institutional Arrangements
- Corporate Organization Alternatives
- Sequencing and Scheduling
- Budgets and Financing
- Operation and Maintenance
- Formulation of Action Plan
- Costs

CONCLUSIONS AND RECOMMENDATION

Conclusions

Recent reports on federal water policy make it evident that those responsible for policy have failed to recognize the contrasting differences between headwater diversions and recycling from tidal basin enclosures. As a result, there is opposition to studies into the potential for resolving major water supply problems affecting the international Great Lakes, the Canadian and U.S. mid-west and the protective development of the water resources of the James Bay Basin. This failure will detrimentally affect relations between Canada and the U.S.A. It will also affect Canadians in western Canada who look forward to dependable new water supplies.

Recommendation

It is proposed that Canada's federal government should withhold the adoption of water policy supply management principles which would prejudice studies into water recycling from a James Bay tidal basin enclosure, as proposed by the GRAND Canal Concept, and endorsed by Premier Bourassa of Quebec and other Canadians.

THE GRAND CANAL SCHEME :

SOME OBSERVATIONS ON RESEARCH AND POLICY IMPLICATIONS

DONALD J. GAMBLE*

ABSTRACT

The GRAND Canal is a multi-billion dollar scheme that envisages creating a "new" source of freshwater in James Bay and a complex system of pumps, canals, and river systems to move that water to the Great Lakes and on to regions facing water shortages on the Prairies and in the United States Midwest and Southwest. This paper examines the scheme from a policy, economic and environmental perspective. While the object of "getting water from the wrong place to the right place" is novel, it raises serious questions for Canada. The author outlines the policy concerns, including the trade implications, related to a continental water grid that is inherent to the GRAND Canal concept. The environmental implications are discussed and the economic rationale is questioned in light of the continental supply-demand and price options. The scheme is considered to be fraught with issues that Canadians can ignore only at their own peril. The author suggests that the scheme is more symbolic of the potentially fatal mismanagement we are all quietly perpetuating than it is of any solution that will lead to a sustainable future.

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THE GRAND CANAL SCHEME:

SOME OBSERVATIONS ON RESEARCH AND POLICY IMPLICATIONS

Is the GRAND Canal scheme an "environmental project", one that "fixes the plumbing system" of the continent?[1] Thomas Kierans, the chief proponent, claims that it is. The scheme is novel, quite apart from its staggering price tag of $80 billion to $130 billion. But it is only the most recent of many mega-schemes engineers have envisaged to capture the waters of Canada's northward-flowing rivers for use in the South--rivers that otherwise are said to "waste their way to the sea".

Kierans's scheme--GRAND being an acronym for Great Recycling and Northern Development--envisages a dike across James Bay and the creation of a new freshwater lake through the impoundment of rivers that now empty into the bay. This fresh water would then be pumped back to the Great Lakes Basin and beyond. Water which would otherwise be "totally lost" would, therefore, be "recycled" and, Kierans argues, put to better use by addressing four problems simultaneously:[2]

- fluctuations in Great Lakes water levels and water shortages within the basin;
- a shortage of water on the Prairies;
- shortages of water in the U.S. Midwest and Southwest; and
- the need to avoid any future diversions of northward-flowing rivers (as advocated by other major schemes to deliver Canadian waters to the South).

Kierans is adamant that the GRAND Canal scheme, whatever the criticisms, is the only way that the water problems now facing 160 million Canadians and Americans can be addressed. It is a project for the 21st century, he says. "The idea is to get wasted water from the wrong place to the right place. Why should the Prairies remain water deficient?" Rejecting the export label others have attached to his idea, and insisting instead that he is creating new fresh water and recycling it, Kierans is convinced that he has the solution. It is a conviction he pursues with zeal and disarming salesmanship.

Trade Implications

In his book Power from the North, Quebec premier Robert Bourassa strongly promotes studies of the GRAND Canal scheme. The venture is backed by powerful engineering companies--the UMA Group, the SNC Group, Bechtel Canada Ltd., and Rousseau, Sauve, Warren Inc. Kierans says that Lavalin, Canada's largest engineering company (and Energy Minister Marcel Masse's previous employer) is courting GRANDCO. Even Atomic Energy of Canada Ltd. (AECL) is contractually involved, with hopes of supplying CANDU reactors to power the pumps that will have to move water south from the James Bay watershed in amounts equivalent to 30 per cent of the discharge of the Great Lakes. In addition, the GRAND Canal scheme has been described by Canada's free-trade negotiator, Simon Reisman, as the most important bargaining leverage Canada could exercise. In a 1985 article on Canada-United States trade, Reisman stated: "This project could provide the key to a free-trade agreement with the United States containing terms and conditions that would meet many Canadian concerns about transition and stability."[3]

Corporate Connections

Kierans has been advocating the project since the early 1960s. Within the last several years it has taken a more substantive corporate form. GRANDCO is a privately held St. John's company incorporated on 15 October 1984. Its nine directors are drawn from engineering companies, AECL, academia, and elsewhere in the private sector. The chairman of the board, Louis Desmarais, was a Liberal member of Parliament from 1979 to 1984 and is now president of J.D.E. Consulting Services Ltd. and chairman of Canadian Home Assurance Co. With past involvement at the most senior levels of Power Corporation and Canada Steamship Lines, Desmarais is GRANDCO's high-powered political and business "door opener".

Trained as a mining engineer and a veteran of the Churchill Falls project, Kierans is the major GRANDCO shareholder. He and an assistant are the part-time staff. Investors are the various engineering companies, which obtain shares through work in kind and cash. A separate entity, the GRANDCO Joint Venture for Engineering, is headed, again on an as-needed basis, by Gilles Mariner, who recently returned to the SNC Group from the James Bay Energy Corporation. The joint venture is made up of the engineering companies on the GRANDCO board and has the exclusive contract for technical studies associated with the scheme.

Money is a problem for GRANDCO. Kierans says the company has spent the equivalent of $750,000 in cash and services in kind since its establishment. Seven studies have been completed, covering subjects from a corporate development strategy to James Bay dike locations and routing of water to the Midwest and Prairies. These studies are not public. A 1985 request for $763,000 from the federal Department of Supply and Services (DSS) and the National Research Council (NRC) created sufficient controversy in Ottawa to cause it to end up in the Prime Minister's Office. The request was turned down, but Kierans eventually managed to obtain $30,000 from the public purse through the NRC branch in Newfoundland. The public servants involved in responding to Kierans's requests at the time were Art Bailey, Senior Assistant Deputy Minister at DSS, and Keith Glegg, Vice-President of Technology Transfer at NRC. Glegg says his and NRC's interest has always been to investigate matters so that there can be a better understanding of the issues raised by the scheme. Bailey retired from DSS in June 1984 and for one year acted as the head of public relations in Ottawa for GRANDCO. Although no longer directly associated with the company, he is listed by the Department of Consumer and Corporate Affairs as one of its founding directors.

Kierans says another $1.5 million to $2 million is needed for engineering and promotion before major investors can be approached for the $10 million needed for detailed studies. The major investors, he says, are resisting because of the "intransigent opposition from Environment Canada". It is not quite that simple.

Policy Concerns

Semantics, it seems, are everything. Although Kierans bristles at the characterization of his project as a water-export scheme (rather than a "recycling" scheme), the GRAND Canal project is predicated on the transfer of huge volumes of water into the United States from the Great Lakes, and that is made possible only by the dedication of waters flowing into Canada's James Bay. However it is phrased, such a transfer runs contrary to stated federal policy which, as the recent Pearse Inquiry on Federal Water Policy estalished, is reinforced by solid public opinion.

Whatever Reisman's personal conviction (and that can only be ignored in the long run at great peril) Canada's Minister for International Trade, Pat Carney, says that "water exports" are not on the table in free-trade negotiations.[4] That position has been verified by statements in the House of Commons by Secretary of State for External Affairs Joe Clark. Environment Minister Tom McMillan and his Liberal predecessor have both opposed the GRAND Canal Scheme. McMillan maintains that large-scale water "export" would only be considered in the context of a comprehensive federal water policy, which is now being developed. Furthermore, in 1985 the governors of the Great Lakes states and the premiers of Ontario and Quebec signed an agreement to guard against "transfers" or "diversions" to the Midwest and Southwest. These policy positions could change, as Kierans insists they will, when the full impact of water shortages are felt in the decades ahead.

Politics aside, moving, transforming, diverting, or exporting water on the scale envisaged by GRANDCO is a Canadian solution to mid-continental water problems that must be subjected to the most thorough and penetrating questioning--now, at the conceptual stage. There is some good work that provides a useful beginning.

Little Need

In an article entitled "Canadian Water: A Commodity for Export?" Richard Bocking has taken a comprehensive, continental view of water supply-and-demand issues. He provides convincing documentation showing that no responsible authority in the United States, apart from engineering firms and others with a project-specific, vested interest, has ever claimed that there is a need for Canadian water. To quote Bocking:

> From promotion to planning to construction, large-scale water projects can easily take 20-30 years or more. Even if rationally conceived, in an era of rapid social, economic, and technological change they risk being totally inappropriate long before they approach completion. With present proposals such as the NAWAPA or GRAND schemes, we start with no conceivable market, unquantifiable but very great environmental risk, inevitable large-scale social disruption, and the opposition of the vast majority of those Canadians who have expressed views on the subject. The possibility of a favourable outcome to such an enterprise reaches the vanishing point.
>
> Focussed research aimed at deepening our understanding of our freshwater resources and careful analysis of the impact of past water developments are among the pressing needs in water research. Exploration of the wide range of social, economic, and technological alternatives to massive water developments is essential. Then perhaps, when faced with real problems, we will be able to choose wisely, allowing for the ignorance and uncertainty that will always be dominant.
>
> If the best alternative involves manipulation of streams and rivers, perhaps with such a basis of understanding we will be capable of doing that with sensitivity and elegance. For the experience of recent decades demonstrates that conventional large-scale structural solutions to water problems, whether domestic or international, comprise a simplistic, expensive and outdated approach to water resource management.[5]

Peter Rogers, Professor of Environmental Engineering at Harvard University, makes much the same point. In a keynote address to a November 1986 workshop on water issues sponsored by the Science Council of Canada,[6] Rogers describes the discussion of export on the Canadian side as having "taken on a xenophobic tinge". Noting Anthony Scott's "careful, cool, and rational examination of the issues" for the recent Pearse Inquiry on Federal Water Policy[7] (where Scott concludes that the cost of water transfers would be well above what the U.S. market would bear on any conceivable level of subsidization by the U.S. government), Rogers goes on to say: "When viewed from the U.S. point of view, the question of water export (or import) is of considerable diminished importance."

A world view of water issues is helpful. In the Soviet Union, for example, there have been major northward-flowing river diversion proposals motivated by continental water redistribution ideas somewhat similar to the GRAND Canal scheme. But the Soviets' initial enthusiasm[8] has been tempered. Recent scientific delegations to Canada have indicated that such schemes are now seen as quite undesirable. In a 1984 publication the Worldwatch Institute considers past experiences and future plans, including those in the U.S.S.R., Canada, and the United States. It concludes:

> In an era of growing competition for limited water sources, heightened environmental awareness, and scarce and costly capital, new water strategies are needed. Continuing to bank on new large water projects, and failing to take steps toward a water-efficient economy, is risky. Vital increases in food production may never materialize, industrial activity may stagnate, and the rationing of drinking-water supplies may become more commonplace.
>
> Alternatives to large dam and diversion projects exist. Water crises need not occur. In water-short areas of industrial countries, people and economic activity must begin adapting to water's limited availability. Supplies in Soviet Central Asia, for example, simply cannot support a booming population and an expanding farming economy for long. Oasis cities such as Phoenix and Los Angeles can no longer expect to grow and thrive by draining the water supplies of other regions. Conservation and better management can free a large volume of water--and capital--for competing uses. Thus far, we have seen only hints of their potential.[9]

Canada can learn from the international context of water management. In his Science Council paper, Rogers described it this way:

> The resource endowment that sets Canada apart from all other countries is something to be justifiably thankful for--but it also brings with it large responsibilities. How much of this endowment should Canada save for future generations (of Canadians and populations of other countries), and how much of it should be pledged for economic gain in the short run?
>
> In the area of water resources we should remember that "we get exactly what we pay for." In both Canada and the U.S. the prices charged for water are so low as to be not believable. We deliver a valuable commodity to very wealthy consumers, who would be willing to pay substantial amounts more for it yet receive the commodity practically for free. In no other sector of our economies do we encourage such profligate behaviour. The time has come for a concerted effort to challenge the "water-is-different" syndrome and raise the cost of water for all water users. I believe that the most important lesson to be learned is that people who use and abuse valuable commodities should pay full price for

what they use, and the full cost of dis-abusing what they abuse.

Combining an aggressive pricing policy with tough environmental laws will enable Canada to get control of its water resources in a way that will be efficient from the point of view of the market and the environment. Everybody will be better off.[10]

Economic Factors

Is a $100-billion-plus scheme like Kierans's GRAND Canal really in the national interest? Certainly it is unique. It is based on capturing fresh water at arctic tidewater and moving it back through canals, rivers, lakes, and diversions to benefit areas throughout North America that are "water deficient". But the cost is immense. There are obvious, powerful, vested interests involved. But who would end up paying and how? The technical appeal of GRANDCO's scheme is one thing. The political, scientific, social, and environmental implications of large-scale manipulations to address water shortages in the Midwest and fluctuating levels in the Great Lakes are another matter. The economic aspects are something else again.

Kierans points to the general economic boost provided by major water schemes elsewhere. The projects he cites are all predicated on a huge capital and operating cost subsidy and were undertaken when that subsidy was the norm. That past norm is implicit in the GRAND Canal proposal. It is a controversial assumption upon which the financial viability of Kierans's venture is balanced. It is not, as Kierans often implies, quite as simple as market need being addressed by private enterprise. The GRAND Canal scheme cannot be undertaken on a "user pay" basis.

Applying the ledger-keeping rigors of the accountant too early in a visionary enterprise can be quite inappropriate, even though apparently rigorous. Nevertheless, when looking at mega-projects like the GRAND Canal, it is helpful to distinguish between economic impact and economic benefit. The former is the financial stimulation resulting from the project, as measured by economic indicators such as Gross Domestic Product; it assumes that if the project did not go ahead, nothing else would take its place. The economic benefit is the net gain or return realized by the investment in the project.

When addressing the advantages of the GRAND Canal, Kierans talks about the Central Valley Project in California and a 1985 study of the impacts of irrigation projects in Alberta. Both point out that only a small proportion of total benefits accrue to the end-user. Although this is true, the two assessments Kierans cites can be fundamentally misleading. They confuse economic impacts with economic benefits.

Building on the cost-benefit approach advocated by Scott's background paper to the Pearse inquiry, Dr. Andrew Muller, of McMaster University's Department of Economics, has provided the only systematic assessment to date of Kierans's water development proposal. Muller concludes that, even setting aside the opportunity costs of exported water and the social and environmental costs incurred during construction and operation, "the quantified costs exceed the benefits by a factor of 6 or 8". Admitting that his estimates are crude, Muller goes on to say:

> These estimates were developed in order to gauge the economic feasibility of the GRAND Canal project and to identify the areas in which further information is most urgently needed. The estimates suggest that the GRAND Canal project is not economically viable. Net Benefits are consistently negative...
>
> This conclusion arises from the limited benefits which flow from the project. Estimated benefits were small for four reasons. First, both the estimated willingness to pay for exported water and the potential volume of exported water were low. Secondly, the losses from flooding and low water on the Great Lakes were estimated to be two orders of magnitude smaller than the estimated costs of GRAND Canal water. Thirdly, care was taken not to confound the economic impact of the project with economic benefits. Finally, only a limited credit was allowed to the project for employment creation.
>
> If further study of this project is undertaken, the most pressing need is to identify a realistic market for the large volumes of water contemplated. Without such a market, additional discussion seems pointless. If, at prices in the order of \$100 to \$200 per thousand cubic metres, a market for up to 67 billion cubic metres of water per year can be found, then high priority should be placed on refined estimates of the engineering cost of the project. To be taken seriously, the proponents must demonstrate that it might be possible to deliver a specified flow of water to the Great Lakes for combined capital and operating cost in the area of 100 \$C/Ml (Canadian dollars per 1000 cubic metres). This is one third the cost estimated (of Kierans's current proposal to direct less than 25 per cent of the total run-off to James Bay).
>
> Much has been made of the social and environmental costs of a GRAND Canal project. Without much more solid evidence of the financial viability of the scheme, it seems premature to attempt to evaluate these costs with reference to this specific project.[11]

Environmental assessment of the GRAND Canal may be premature. Kierans quite rightly stresses the environmental benefits of bringing water to water-deficient regions. He warns of the serious environmental and social implications of not doing so. And he seeks to downplay criticisms by citing the project endorsement received in the early 1960s from Dr. Ken Hare, a prominent environmentalist at the University of Toronto. Hare, now with the Ontario Nuclear Safety Review Commission, says Kierans overstates his "endorsement". Hare says he is certainly not an advocate of the project; rather, he was intrigued by the option it provides to direct more water into the Great Lakes for level and outflow stabilization. Beyond that, Hare questions the northern social and environmental impacts as well as the feasibility and inter-basin implications of water transfers to the West and South.[12] This kind of concern is best exemplified by the Garrison River Diversion and Canada's hard-line opposition, which is based on the impact of biotic transfer. The prospect of this in a continental water grid is daunting. What, for example, would be the effect of having the sea lamprey distributed throughout the waters of western Canada and the United States?

Unknown Impacts

The best "first cut" at the potential ecological effects of the GRAND Canal on James Bay and Hudson Bay has been done by Robert Milko of the Library of Parliament Research Branch in Ottawa. Milko's paper raises serious questions about possible long-term ecological, oceanographic, and climatic effects. Milko's work, based on a comprehensive literature survey, suggests that changes to the salt-freshwater boundary, known as the pycnocline, may affect short- and long-term productivity at all levels of the food chain within Hudson Bay and down the Labrador coast. Fish, seals, polar bear, whales, and millions of migratory birds will be affected, with profound national and international implications. But assessment of the project's impact is speculative, largely because of the lack of scientific knowledge about the region on the part of non-native specialists and the meagre data base currently available. Milko concludes:

> This analysis of the potential ecological effects of the GRAND Canal project indicates that a great deal more research is warranted before such a large-scale diversion is seriously considered. The implications for some of the ecological parameters addressed suggest that large-scale, possibly irreversible detrimental changes to the northern ecosystem would result. Down-stream effects, which receiving areas of the diversion may encounter, have not been addressed but also need to be studied.
>
> Specifically, more oceanographic research in Hudson Bay, particularly documenting pycnocline development and its role as a regulator of sea surface temperature, ice pack and

> primary productivity, is needed. The relationship involving circulation and exchange between Hudson Bay, Foxe Basin, Hudson Strait and the Labrador Sea with respect to freshwater contributions and nutrient exchanges must be established. As well, more complete biological inventories and an understanding of their ecological relationships are needed in all potentially affected bodies of water.
>
> These are all complex questions for which long-term monitoring will be necessary in order to establish relationships of ecological parameters through the total range of variability that could be experienced naturally. In particular, data at the limits of the range of variability will be helpful in modelling responses to conditions as extreme as envisioned in the GRAND Canal scheme.[13]

No assessment has been made of the effect of the GRAND Canal scheme on the Cree and Inuit of the James Bay and Hudson Bay region. Kierans talks of jobs and of developing this economically depressed area--a mega-project solution that has been suggested and tried before in northern Quebec, the Mackenzie Valley, and elsewhere in the North. It should have a familiar ring to aboriginal peoples. Nevertheless, it is a very particular utilitarian mentality that considers the freshwater component of James Bay and Hudson Bay as "totally wasted". And it is disturbing to see the North again viewed as an empty space, the natural resources of which can be "better" used only to satisfy the appetites of the South. No doubt, these shortcomings will be addressed in due course. Kierans simply says: "First things first". To GRANDCO, that means engineering and promotion, for now. But in the process it would be only prudent to acknowledge the existing aboriginal rights to the northward-flowing rivers of the region. Recent studies at the Institute for Resource Law in Calgary suggest that these constitutionally enshrined rights could create quite a surprise for enthusiasts like Kierans, Reisman, Bourassa, and others.

The GRAND Canal is definitely a grandiose scheme. Where Kierans is on solid ground is in his emphasis on present and future problems in the Great Lakes. He is also quite correct in identifying future water problems in some areas of North America. But linking that to James Bay on one hand and to a continental water grid on the other takes some daring, to say the least. Some see that as a kind of visionary genius that goes beyond limited piecemeal approaches. To them, Kierans's determination and dismissal of contradictory views is necessary for the attainment of a goal beyond all the immediate complexities. Many others see that daring as a throw-back to the tunnel vision that creates problems while purporting to solve them--a structural, supply-fix approach of questionable feasibility that ignores the true nature of the problem as well as the consequences so evident from the past.

Long-term trends, including climatic change, suggest the need for some kind of new supply to the Great Lakes if levels are to be maintained. It was a point acknowledged, however meekly, in the Pearse report. That supply focus may seem curious in a year when high levels are a problem--which, of course, is why Kierans's idea of "stabilization" has appeal--but stabilization requires massive inflows (about 50,000 cubic feet per second, according to Kierans) in some years and dedicated massive "exports" whatever the natural cycle of the lakes. When the price tag is $100 billion or more, government subsidies and financial guarantees will be needed on a scale never before seen in North America.

It is all too easy to address a need by conjuring up simplistic, technological fixes to complex social, political, economic, and environmental problems. The grander the scheme, the more vast and general its scope, the easier it seems to be to generate enthusiasm. And it is also all too easy, with quite another kind of enthusiasm, to oversimplify issues--to focus too narrowly and criticize big schemes and dreams from which solutions can sometimes be developed. Zeal in proving a point replaces the commitment to really investigate. The consequences are unhealthy.

In a January 1987 article on water,[14] Peter Newman mentions the GRAND Canal scheme and quotes Tom Kierans warning that Canada should negotiate water export while it still has the option. "Of course, the United States will not simply come and grab our water", Kierans explains. "They'll find another rationale--like saving us from the Russians." In sounding the alarm, Kierans is not alone. Newman ends his article with a quote from Roy Faibish, executive assistant to the minister of agriculture in the 1950s and now a television executive in England: "The strategic planners sitting in Peking, Moscow, Washington, Paris, and London are looking at Canada...Either we start exporting our water or else!"

This is a powerful emotional appeal based on fear. It is the kind of appeal that bypasses proper evaluation and assessment, and stampedes the decision-making process. Although it is not uncommon, it is the worst kind of nonsense coming from otherwise intelligent people. Faibish could, perhaps, be excused. But it is strange coming from Kierans, who takes such exception to the "export label" being applied to his project. It is stranger still when GRANDCO purports to provides such a rational approach while discounting as emotional or biased the seriously considered critiques of others.

Serious Questions

Water is not just another resource. It is the basis for all life. There is no substitute. It has a special place in the human psyche. Society, particularly Canadian society, quite rightly places water in a category quite different from anything else. Water is an allencompasssing symbol of value and life that transcends comprehension as market worth and even intrinsic worth. When threatened, that value naturally prompts great emotion.

To deride this trait in Canadians only cheapens the values that are a vital part of our identity. If this stretches conventional reason for some, then perhaps the strong public reaction to ideas like the GRAND Canal is more understandable in the context of opinion polls that consistently place environmental issues, and water issues in particular, at the top of the list. This public concern is shared internationally, as the recent report of the World Commission on Environment and Development points out so well.

The dedication of waters from Canada to the United States on the scale envisaged by the GRAND Canal does raise serious continental questions. For example, such a scheme, if it were feasible, would create a permanent and direct American interest in one of our most basic resources. The waters of the Great Lakes are already shared, but that arrangement would be extended north and south. If the scheme actually does what its proponents claim, it would create a lifeline from the U.S. Midwest and Southwest up through the Great Lakes into Canada's North. Americans would be dependent on that supply of water, water they will increasingly see as their own, their right, and vital to their well-being. That may bring great opportunities. But there are real possibilities for tension and serious misunderstandings that cannot be overlooked. The implications of establishing the GRAND Canal scheme with its origins in Canada and criss-crossing the nations's heartland are at the core of the decision-making process. These decisions cannot be made lightly. They are not in the purview of engineers. Problems, where they do exist, can always be addressed in more than one way. The choices must not be artificially defined nor should they be restricted by short-term, vested interests. A fear whipped up to suit a cause should be understood to be the emotional blackmail that it is.

Water shortages exist now, and they may get worse in some regions, but it is important to remember that these shortages are defined by human use and abuse of water resources. Resource specialists and users worldwide see augmented supply as only one aspect of the solution to shortages. Using very expensive and massive water transfers is increasingly suspect. More often the real issue is seen to be in the laws, regulations, economies, and management techniques that drive our manipulation of water. Within that, demand management through efficiency of use, conservation, and realistic pricing offer immediate means to address shortages. If history can teach anything, it will show that few water shortages are solved in the long run by throwing more water at the problem. More elegant solutions are worth pursuing as the avenue of first recourse.

Perhaps, in the end, the GRAND Canal scheme or some variation of it, may be necessary, even desirable. If so, we must accept that it is fraught with issues that can be ignored only at our own peril. Today, the scheme is more symbolic of the potentially fatal water mismanagement we are quietly perpetuating than it is of any solution that will provide a sustainable future. In all the talk and promotion, hopefully we will be wise enough to see that sustainable future as the real issue to be addressed. If nothing else, Kierans could be just one more agent provocateur that compels us to do so.

ENDNOTES

1. All quotes are from 1987 telephone calls and meetings in Ottawa with Thomas Kierans.

2. See GRANDCO, The GRAND Canal...An Introduction, (1986) and T.W. Kierans, Great Lakes Levels Stabilization, the GRAND Canal Concept and Canadian Water Policy, (7 October 1987), presentation to the Provincial co-ordinators for Industrial Research Assistance, National Research Council, St. John's.

3. See Simon Reisman's, Canada-United States Trade Options at the Crossroads: Options for Growth, Canadian Business Review, (Autumn 1985), p. 23.

4. Letter to the author from the Minister of International Trade, dated 9 December 1986.

5. See Richard Bocking, Canadian Water: A Commodity for Export? Canadian Bulletin of Fisheries and Aquatic Science, No. 215 (1987)

6. Opening address, 3 November 1986, unpublished but available from the Science Council of Canada, 100 Metcalfe Street, Ottawa, Ontario K1P 5M1.

7. See Anthony Scott, The Economic of Water Export Policy, Inquiry on Federal Water Policy, (March 1985).

8. Personal communication with Dr. F. Roots, Science Advisor to the Minister of Environment, Environment Canada, Ottawa.

9. See Sandra Postel, Water: Rethinking Management in an Age of Scarcity, World Watch Paper 62, (1984), p. 53.

10. op. cit.

11. See R. Andrew Miller, Some Economies of the Grand Canal, Technology Assessment in Subarctic Ontario Research Report No.26, (1986), p.19.

12. Personal communication 23 June 1987.

13. See R. Milko, Potential Ecological Effects of the Proposed GRAND Canal Diversion Project on Hudson and James Bays, Arctic Volume 36, No. 4, (December 1986).

14. See Peter C. Newman, The Unknown Element, Saturday Night, (January 1987), p. 178.

THE GRAND CANAL: POTENTIAL ECOLOGICAL IMPACTS TO THE NORTH AND RESEARCH NEEDS

ROBERT J. MILKO[1]

ABSTRACT

The GRAND Canal scheme, which by the construction of a dike across James Bay would divert 61% of Hudson Bay's freshwater budget south, has ecological implications for the North. The formation of ice in Hudson Bay could increase as its pycnocline develops earlier in the spring and deepens in the summer, and ice breakup is delayed because of the removal of the warm James Bay outflow in the spring. A reduction in primary productivity could result because of changes in the pycnocline's development, the removal of nutrients normally associated with spring's melting ice and a decrease in stable stratification periods as the dike removes the dampening action of James Bay on tidal and wind-generated disturbances.

Changes in nutrient content and freshwater circulation out of Hudson Bay could potentially affect productivity downstream on the Labrador Shelf, and changes in productivity and ice pack within Hudson Bay could detrimentally affect fishes and marine mammals. Changes to coastal staging areas in both Bays would most likely destroy a major portion of the North American migratory bird population. A resurgence of interest in the GRAND Canal scheme necessitates further research to provide data for the many unanswered questions concerning the potential ecological impacts of the diversion.

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[1] Research Officer with the Research Branch of the Library of Parliament. The views expressed in this paper are those of the author and are not to be attributed to the Library of Parliament.

INTRODUCTION

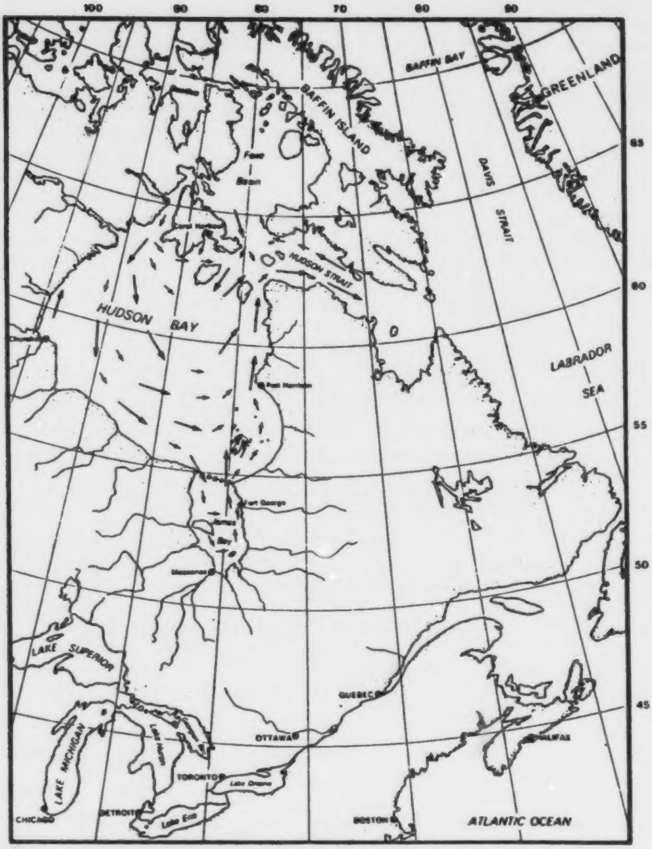
This paper presents a preliminary environmental impact assessment of what, if constructed, has the potential to be the largest water diversion in history: the GRAND Canal. The project itself, if pursued, would involve the construction of a dike across James Bay (Figure 1) creating a large freshwater lake, and the transferring of this freshwater by way of canals and existing water courses to the Great Lakes and various other areas of the United States and Canada. Although the parameters of the project have not yet been clearly defined, one likely scenario would involve the total withdrawal of all freshwater flowing from James Bay into Hudson Bay (Bourassa, 1985) (i.e., 61% of the freshwater budget of Hudson Bay) or 317 $km^3.yr^{-1}$ (Prinsenberg, 1980). This assessment involves a synthesis of the presently published data and reflects potential ecological impacts to the North only. In order to speculate on these impacts, it is necessary to first describe the oceanographic parameters involved and then relate the changes in these parameters to their potential impact.

OCEANOGRAPHIC DESCRIPTION

Hudson Bay is part of a large inland sea which is connected to the Atlantic Ocean by Hudson Strait and the Labrador Sea, and to the Arctic Ocean by Fury and Hecla Strait. Both Bays are relatively shallow; Hudson Bay has an average depth of 125 m and James Bay has an average depth of 28 m.

Circulation

Hudson Bay is believed to behave as a huge estuarine basin (Pett and Roff, 1982). A simple description of its circulation can be envisioned as cold, dense subsurface water with a salinity of 33.4‰ or greater entering from Hudson Strait, while the surface water, moving north along the eastern shore, is a less dense water mass diluted by runoff and warmed by solar radiation (Prinsenberg, 1986b). This exchange creates a haline circulation system or density currents which contribute somewhat to the surface circulation pattern (Figure 1). The surface circulation, however, is predominantly wind-driven (Prinsenberg, 1986a). James Bay's circulation is driven by the same processes as in Hudson Bay with runoff playing a much larger role. This also results in an estuarine circulation where cold saline water enters James Bay beneath the fresher surface layer and exits in a strong northerly surface outflow along the eastern shore into Hudson Bay.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BAFFIN BAY
GREENLAND
BAFFIN ISLAND
DAVIS STRAIT
Foxe Basin
HUDSON STRAIT
HUDSON BAY
LABRADOR SEA
Port Harrison
Fort George
James Bay
Moosonee
LAKE SUPERIOR
LAKE MICHIGAN
Lake Huron
QUEBEC
OTTAWA
TORONTO
Lake Ontario
DETROIT
Lake Erie
CHICAGO
BOSTON
HALIFAX
ATLANTIC OCEAN

FIG. 1 Location map of Hudson Bay and James Bay illustrating summer surface circulation patterns and possible location of the dike (Prinsenberg, 1986a).

Freshwater Input

To better understand the effects of freshwater input on the salinity and water column stability of Hudson Bay, it is necessary to differentiate between freshwater flux and freshwater input. Freshwater input or addition is dependent on runoff which is a function of both spring melt and precipitation (Figure 2). On a seasonal basis, a maximum rate of runoff for both Bays occurs with the spring freshet of May and June. In James Bay, however, a secondary peak of runoff occurs during the pronounced rainy season (October) of the southern region. In that period, the precipitation rates are nearly double those of Hudson Bay and balance the loss of water resulting from evaporation (Prinsenberg, 1986b). This affects freshwater flux. In contrast, Hudson Bay acts more as an oceanic region and loses more in evaporation than it gains from precipitation.

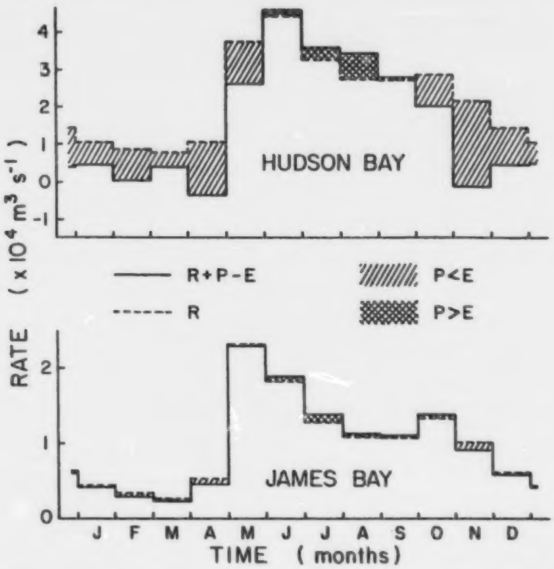

FIG. 2 Rates of monthly freshwater input for Hudson Bay and James Bay including contributions from runoff (R), precipitation (P) and evaporation (E) (Prinsenberg, 1986b).

The timing and pattern for James Bay's breakup is strongly dependent upon the large quantity of relatively warm freshwater of the spring runoff (Prinsenberg, 1980). Consequently, this relatively warm surface outflow from James Bay initiates the early breakup of the ice in southeast Hudson Bay. Because ice is relatively fresh (5‰) and because of the large quantity involved, the melting of winter ice is found to contribute as much to the freshwater flux as does runoff (Prinsenberg, 1984). Decay of the ice cover commences in late May

(Markham, 1981), and rapidly releases this source of stored freshwater throughout June and July. This ice, having been formed from the saltwater itself does not affect the overall salinity of the Bay but redistributes the salt and freshwater vertically. In this regard, it contributes as much as the surface runoff to the water column stability, an aspect of prime importance.

When calculated over the year, the Hudson-James Bay region receives, by these processes, a 64 cm layer of freshwater (Prinsenberg, 1980). Most importantly, of this, James Bay accounts for 61% or 317 $km^3.yr^{-1}$ (Prinsenberg, 1980). When one includes the equal or greater contribution from ice melt in the flux calculation, a freshwater layer of approximately 1.2 m is received per year.

Pycnocline Development

Analysis of the literature indicated that many ecological parameters are dependent on the "behaviour" of the pycnocline, a boundary separating a freshwater layer over a saltwater layer with little mixing. Figure 3 illustrates the annual cycle of salinity profiles and pycnocline development for Hudson Bay as predicted by a mixed-layer model of Prinsenberg (1983) developed in accordance with measured summer profiles. Starting at spring melt (day 151 or June 1), the beginning of the pycnocline, recognized by a sharp difference between surface salinity (top 1 m) and salinity at depth, becomes discernible. By August 1, the surface salinity is at a minimum while the temperature is at a maximum. As the summer progresses, the pycnocline continues to deepen as wind action causes mixing in the surface layer increasing its depth. Eventually the pycnocline reaches 93 meters at the end of the following winter. Below the pycnocline, water properties remain relatively constant (i.e., cold and salty), but above the pycnocline, vertical mixing caused by the wind redistributes solar input to produce a relatively homogeneous water temperature and salinity. This contains 74% of the total heat input to the Bay, i.e., runoff and solar radiation (Prinsenberg, 1984).

EFFECTS OF FRESHWATER FLOW AND DIVERSIONS

Ice Pack and Climate

Considerable concern has been expressed about possible modification to ice pack and climate as a result of large-scale water diversions of north-flowing rivers. Besides local and regional effects which are more easily envisioned, large-scale climate affects might be possible. Prinsenberg's (1983) model has been used to examine the sensitivity of the pycnocline and water column stability of Hudson Bay and their

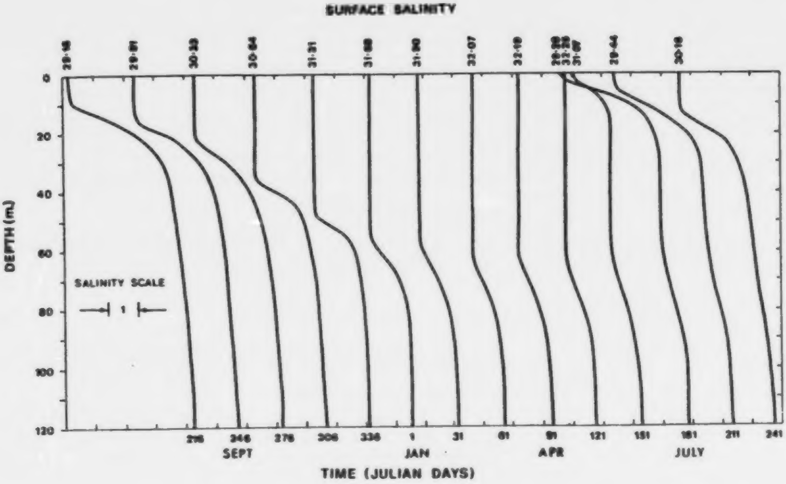

FIG. 3 Annual cycle of salinity profiles for Hudson Bay as predicted by a mixed-layer model (from Prinsenberg, 1983). Each profile is stepped to the right by 1.5 salinity units and its surface salinity is noted at the top of each profile. The time of occurrence at 30-day intervals is denoted in Julian days and months at the bottom of the profiles (Prinsenberg, 1986b).

relation to, among other parameters, ice pack modification on a large scale. Results of the model which simulated a 25% ice layer reduction - the equivalent of a 50% reduction of James Bay's freshwater flow - indicate that due to runoff modification and warm freshwater withdrawal, a new shallow surface pycnocline of Hudson Bay would be formed earlier in the spring. This would decrease the surface layer temperature and salinity and stimulate an increase in ice formation (Prinsenberg, 1983; pers. comm., 1985). As well, in the summer, the surface layer salinity would be higher and the temperature would be lower, which would decrease the water column stability. As a result, the pycnocline would also deepen and increase the deviation from normal conditions (Prinsenberg, 1983).

In addition to an increase in ice formation as vertical mixing is reduced, the possibility of ice pack and climate modification seem more likely when one considers that damming James Bay and removing its spring outflow into Hudson Bay would result in a delay in ice breakup which is normally promoted by outflow from James Bay. The present local and regional effect at the Hudson and James Bay's ice pack on the weather patterns and flora in central Canada is indicated by the southward dipping of treeline as Hudson and James Bay are approached from the east or west. Considering the dependence of treeline on the delicate balance of climatic parameters, any modification to ice pack duration could affect the regional climate and perhaps larger climate patterns.

Primary Productivity

The same changes in the pycnocline's behaviour described earlier also indicate that a total diversion of James Bay freshwater might result in only a 1‰ increase in salinity in the summer surface layer of Hudson Bay (Prinsenberg, 1983). Although ice pack may be changed quite readily, salinity modification itself may have less direct biological impact than one might suspect. However, further ramifications of the reduced stability and the deeper pycnocline that the model predicts could involve a reduction in primary productivity.

Offshore phytoplankton are presently found in a 20 m layer below the pycnocline where their chlorophyll concentration ranges from 2 to 63 times surface chlorophyll layers. Studies indicate that it is likely that this subsurface layer contributes significantly to the overall primary productivity of Hudson Bay (Anderson and Roff, 1980). However, no estimation of percent contribution has been calculated. If phytoplankton are somewhat restricted to this layer because of nutrient limitations above and light limitations below, a deeper pycnocline as predicted by the model, may result in the entrainment of nutrients below the photic limits of these phytoplankton.

Other aspects of circulation may also affect production. For example, if the pycnocline were to deepen (recalling that mixing of the water column generally occurs above the pycnocline) the large, unoxidized nutrient reserves of the lower levels of the Bay which normally require between 4 and 14 years to turn over (Pett and Roff, 1982), might be brought to the surface more rapidly and increase the nutrient composition in the photic zone. Unfortunately, this mixing would now occur in the fall or winter, and it is not known whether the phytoplankton species in the Bay have the ability to photosynthesize at the low light levels that they would encounter beneath the ice. As well, the timing would not be characteristic of Arctic waters where a single peak of phytoplankton production normally occurs in the spring (Anderson and Roff, 1980), a bloom that forms concurrently with the seasonal influx of nutrients from surface waters; which also could be reduced.

The actual contribution of nutrients from James to Hudson Bay is not known. However, preliminary budget calculations for the system indicate that nitrate and total nitrogen contributions from land runoff and deepwater mixing are of the same order of magnitude. As well, nutrient input from melting ice may also play a role. Studies indicate that levels of nitrate and nitrite in the surface ice and in the snow cover are generally a factor of two or three greater than those in the water immediately below the ice (Freeman et al., 1982). It is therefore possible that melting ice and snow may be an important nutrient source during the spring phytoplankton bloom. In view of the large contribution of James Bay to Hudson Bay, withdrawal of the nutrients associated with the James Bay freshwater influx could severely affect the food chain.

Aperiodic phytoplankton blooms are also important, particularly in the coastal embayments of southeast Hudson Bay. Analyses indicate that most production occurs in the intermittent stable periods between random periods of destratification caused by winds and tides. It is, however, the destratification and upwelling which provides the required nutrients (Legendre et al., 1982). Construction of the dike would remove the dampening effect of James Bay which would tend to increase the depth and frequency of the aperiodic destratifications, i.e., James Bay would no longer be open to absorb the large tidal forces. Waters may be less stable and the intermittent stable periods which are required for production might be reduced in number and duration.

Long-Distance Effects

Long-distance and long-term effects are also possible. The freshwater contribution from James Bay is known to be a significant part of the total signal from the Hudson/James Bay system which is detected down the Labrador Coast (Neu, 1982a; Sutcliffe et al., 1983). The strength of this signal may be affected because of a reduced circulation in Hudson Bay and, as well, the salinity of its waters entering the Labrador current would be increased. These changes would be received at the Grand Banks in the autumn, the Scotian Shelf during the winter, and Georges Bank probably during the spring. All these areas are regarded as productive fishing grounds.

The result of a reduction and/or change in the timing of the freshwater signal is not clear. One possibility is the density current would be reduced, the current that is normally formed when a freshwater flow encounters saltwater. For example, as illustrated in the St. Lawrence (Figure 4) and applicable to many estuaries as in Hudson Bay, the surface layer of freshwater flows outward causing the deeper (often nutrient-rich) bottom saltwater to flow shoreward. The magnitude of this density current will be proportional to the pressure difference. It is possible that a reduction of a density current could result in a reduction in productivity if less nutrients were returned by a weakened current. Furthermore, in an unregulated system in northern latitudes, pulses of current occur as a result of seasonal runoff and pulses of freshwater can add nutrients directly. A change in its seasonality or removal of the pulse could be detrimental (Neu, 1975, 1982a,b).

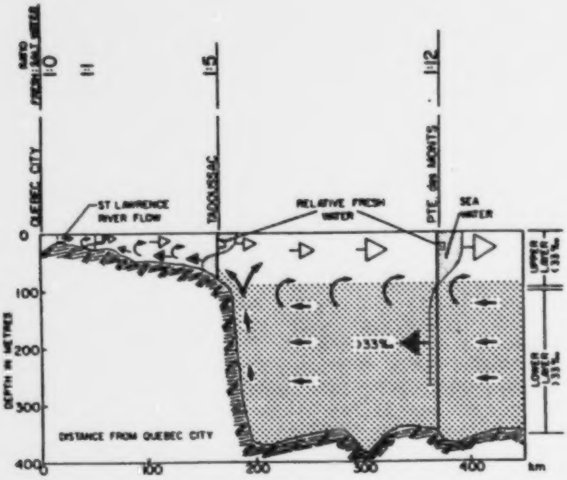
RATIO FRESH:SALT WATER
1:0
1:1
1:5
1:12
QUEBEC CITY
TADOUSSAC
PTE. des MONTS
ST LAWRENCE RIVER FLOW
RELATIVE FRESH WATER
SEA WATER
>33‰
UPPER LAYER <33‰
LOWER LAYER >33‰
DEPTH IN METRES
0
100
200
300
400
DISTANCE FROM QUEBEC CITY
0
100
200
300
400
km

FIG. 4 Schematic representation of haline circulation (density currents) in the St. Lawrence River system (Neu, 1975).

An alternate effect of a reduced freshwater flow from Hudson Bay is inferred from a hypothesis that productivity increases further south along the Labrador Coast because a greater distance allows more time for a food chain to develop (Sutcliffe et al., 1983). This hypothesis is based on nutrient input from a mixing area in Hudson Strait which is then advected south. Analysis suggests that in years of high freshwater outflow from Hudson Bay there is an increase in stratification, and less upwelling and transporting of nutrients south resulting in reduced productivity (Sutcliffe et al., 1983). This would indicate that reduced flow could be beneficial. What has not been addressed in applying this hypothesis, however, is the potential effect of reduced nutrient input from Hudson Bay itself. For example, Hudson Bay and Foxe Basin waters are estimated to contribute 37% of the Labrador Shelf water and are a major contributor to its high nutrient content (Sutcliffe et al., 1983). Therefore, a reduction in nutrient content from Hudson Bay, either directly or through the zone of mixing in Hudson Strait, has the potential to detrimentally affect productivity south along the Labrador Shelf. Based on the above discussions, it thus appears that even the quality of the impact is unclear (i.e., beneficial or detrimental). The one salient and consistent interpretation that is implied, however, is that there is some cause-and-effect relationship between the freshwater signal from Hudson/James Bay and productivity down the Labrador Coast.

Aquatic Food Chain: Plankton, Macrobenthic Fauna and Fish

A reduction in the primary productivity of Hudson Bay would eventually decrease productivity at all levels of the food chain. Resource inventories are scant and the relationships among components of the food chain in Hudson Bay are poorly understood. For example, ciliates are found in high abundance at the Belcher Islands in southeast Hudson Bay. Although their role has not been adequately described in any Ocean, it has been suggested that they do play a significant role in the food chain at the Belchers where they serve as important predators on phytoplankton and as prey for the larger omnivorous zooplankton (Grainger, 1982).

The distribution of macrobenthic fauna in river estuaries of the Bays is linked to salinity and organic matter content in the sediments. Macrobenthic fauna populations will therefore probably change as a result of a reduction of freshwater at river estuaries, particularly in those of the southeast coast of Hudson Bay where salinity might increase the most. Species with a pelagic mode of reproduction will probably invade new saline habitats of the estuaries faster than species without such a mode of reproduction (Grenon, 1982). Although surveys are lacking, it is generally thought that the potential for a commercial fishery in either Bay is low. There are, however, approximately 60 fish species in the estuarine fish communities of both Bays, with a greater variety in the south (Morin et al., 1980). The adaptability of fish species to salinity changes will play a predominant role in determining the composition of estuarine fish communities of the Hudson Bay Coast after dike construction (Ochman and Dodson, 1982).

It is likely that impounding James Bay would have similar implications for ecological productivity in the newly-formed lake. Virtually all marine organisms would be destroyed and freshwater fish species presently dominant in the southern Hudson Bay estuaries are the most likely to dominate in the impoundment (Morin et al., 1980; J. Dodson, pers. comm., 1985).

Marine Mammals

Little information is available on marine mammals of either Bay. Ringed seals and bearded seals are the predominant species and it is likely that they, as well as other marine mammals, would be negatively affected by a reduction in productivity. Ringed seals are found on all coasts of both Hudson and James Bay, where together their populations have been estimated at greater than 500,000 (Department of Fisheries and Oceans Canada, 1985). The only population estimate for bearded seals is a 1958 figure of 84,000 in Hudson Bay (Mansfield, 1968). The two species have different ice requirements. Ringed seals require fast or shore ice for breeding whereas bearded seals are usually associated with moving pack ice and shallow banks. One would expect a shift in the ratio of fast to pack ice would be reflected in a shift in the ratio of ringed seals to bearded seals respectively.

Walrus population estimates in the eastern Canadian Arctic are incomplete. In Hudson Bay, the main concentration is at Coats Island and Southampton Island where they are found during all seasons, with an estimated summer population of 2,000 (Reeves, 1978).

Polar bears are directly dependent on seals as their main food source and would be affected by any long-term changes in seal populations. As well, critical denning areas on the coasts could also be lost due to flooding and construction; however, the exact interrelations of these parameters and natural population regulation have not yet been elucidated.

White whales (also known as belugas) are the main species of whale found in Hudson Bay. The most recent report estimates that a population of 8,000 to 9,000 summer in western Hudson Bay and winter in open areas of Hudson Strait and Ungava Bay (Finley et al., 1982). Other evidence suggests a portion of the population uses the polynya of northwest Hudson Bay and James Bay in winter (Jonkel, 1969; Sergeant, 1973). Additionally, a small population of a few hundred belugas spend the summer on the east coast of Hudson Bay (Finley et al., 1982). Estuaries appear important to belugas, serving as feeding grounds, areas for as yet unexplained social behaviour and as calving grounds (Sergeant, 1973). Loss or alteration of estuaries could further affect whale behaviour, such as migration pattern, reproductive success, or both. As well, the distribution and movements of belugas are greatly influenced by ice conditions, and changes in ice pack regimes may have significant consequences. For example, in conjunction with the possibility of lower water temperatures and increased ice pack, a reduction in circulation of Hudson Bay could threaten the existence of polynyas.

An endangered population of possibly less than 100 bowhead whales inhabits northern Hudson Bay, most probably on a year-round basis, although once again data are limited. A strong, circumstantial argument suggests that ice conditions affect the survival of bowhead whales as they tend to remain near the edge of ice; an increase in ice cover could increase the possibility of entrapment in the ice, and it would also restrict their movement to preferred feeding grounds (Mitchell and Reeves, 1982). It thus appears that a closing of open areas would be disastrous for any non-migratory populations of marine mammals.

Waterfowl, Shorebirds and Seabirds

As shown in Table 1, virtually millions of waterfowl and shorebirds depend on either the James Bay or Hudson Bay Coast as staging areas during periods of migration in the spring and fall. Effects of dike construction would almost certainly be negative, particularly in

James Bay. Lower productivity of coastal marshes, due to changes in nutrient input, salinity and temperatures and/or alteration to their seasonality because of delayed ice breakup, could result in destruction of all or a major portion of the North American migratory bird population (D. Welsh, CWS, pers. comm., 1985).

TABLE 1. Major Bird Populations Affected*

WATERFOWL	STAGING OR FEEDING AREA
200,000 Canada Geese 2.5 Million lesser snow geese	Hudson Bay Lowland
60% lesser snow geese	James Bay Coast
320,000 black scoters	James Bay - South
75% Pop. Atlantic brant geese	James Bay Coast
SHOREBIRDS	
100% H.B. Population Hudsonian godwits 100% N. America Population red knots	lower intertidal in both bays
SEABIRDS	
3rd largest Canadian Arctic population Dominant: thick-billed murre	North Hudson Bay and Strait

* References according to order presented:
(Thomas and Prevett, 1982; Prevett et al., 1979; R.K. Ross, CWS, pers. comm., 1985; R.I.G. Morrison, CWS, pers. comm., 1985; Gaston, 1982).

Additional Effects and Concerns

"James Bay has been called a sediment sump for the centre of the continent" (Kranck and Ruffman, 1982) as rivers are estimated to bring 40 million metric tonnes of sediment per year into James Bay. With a removal of estuarine circulation because of dike construction, it is likely that coarse suspended particles would tend to settle out of the water column sooner, resulting in the formation of river deltas. In contrast, the very fine sediments would tend to stay in suspension longer because a freshwater regime would result in less flocculation and sediment precipitation (K. Kranck, pers. comm., 1985). Potential effects could be a reduction in primary productivity as less light becomes available and an increased potential for clogging gills and filtering mechanisms.

Although engineering plans are still speculative, estimates indicate that over one billion cubic metres of landfill will be required to construct a dike across the opening between the two bays (Bruneau, 1985). The source of this landfill has not been identified, but the removal of such quantities is certain to have some detrimental impacts.

SUMMARY

In summary, this analysis indicates that a great deal more research is warranted before such a diversion is seriously considered. The implications for some of the ecological parameters addressed suggest that large-scale, possibly irreversible detrimental changes to the northern ecosystem would result. Downstream effects, which receiving areas of the diversion may encounter, have not been addressed but also need to be studied.

Specifically, more oceanographic research in Hudson Bay, particularly documenting pycnocline development and its role as a regulator of sea surface temperature, ice pack and primary productivity, is needed. The relationships involving freshwater circulation and nutrient exchange between Hudson Bay, and the productive east coast fishing areas, must also be established. As well, more complete biological inventories and an understanding of their ecological relationships are needed in all potentially affected bodies of water.

These are all complex questions for which long-term monitoring will be necessary in order to establish relationships of the ecological parameters involved. I would suggest that in particular, data at the limits of the range of natural variability will be helpful in modelling responses to conditions as extreme as envisioned in the GRAND Canal scheme.

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SESSION A

INTERBASIN TRANSFER OF WATER:
REGIONAL EXPERIENCES

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AN ENVIRONMENTAL OVERVIEW OF THE CHURCHILL RIVER DIVERSION

R. E. HECKY[1]

ABSTRACT

The Churchill River was diverted out of Southern Indian Lake beginning in 1976, and designed diversion flows were reached by the fall of 1977. The lake level was raised three meters in order to allow gravity-flow diversion through an excavated channel of up to 850 cubic meters per second (85% of mean annual outflow of Southern Indian Lake). The immediate post-diversion physical effects on Southern Indian Lake are due to both impoundment and diversion. Diversion imposed a new pattern of stable winter ice cover, a new pattern of ice-out, cooler summer temperatures and reduced nutrient loading from the Churchill River on the northern portion of the lake. Impoundment caused extensive shoreline erosion within Southern Indian Lake while diversion caused locally intense erosion at rapid sections on the Burntwood River diversion route. The associated biological changes in Southern Indian Lake have led to a decline in the productivity of the reservoir-lake. The impacts on Southern Indian Lake are reviewed in the Canadian Journal of Fisheries and Aquatic Sciences Vol. 41(4). In the abandoned lower Churchill River, lakes have had their mean areas reduced by up to 75%, and the lakes are exposed to extreme fluctuations in flows and levels. The ecological consequences of river diversion on lakes and river sections of the lower Churchill are unfortunately unknown. Along the diversion route, the Notigi Reservoir exhibited a classical reservoir response of increased productivity, but mercury contamination caused by the microbial transformation of naturally occurring inorganic mercury restricts marketing of large, piscivorous fish in this reservoir. Below Notigi Reservoir water levels rose all along the diversion route because of

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higher flows, and many natural lakes along the route now have higher concentrations of mercury in fish than before diversion. Many of the problems associated with the Churchill River diversion will be long term, if not permanent; consequently such projects require close scrutiny in the design phase because changes in the ecosystem may be irrevocable.

THE SOUTH SASKATCHEWAN - QU'APPELLE DIVERSION:
HISTORY AND FUTURE PROSPECTS

L. H. Wiens[1]

ABSTRACT

Diversion of water from the South Saskatchewan River to the Qu'Appelle River began with a small pump diversion in 1958 designed to augment the water available from Buffalo Pound Lake to supply the municipal requirements of the cities of Regina and Moose Jaw. Development of the South Saskatchewan River Project during the 1960s greatly increased the diversion potential, which is far from full realization twenty years after completion of the project. The primary purpose of the diversion is still municipal water supply, with some consideration given to irrigation and recreation requirements.

This paper traces the history of the South Saskatchewan - Qu'Appelle diversion from its natural origin as a meltwater channel during the retreat of the Wisconsinian Glacier to the controlled operation of the present day diversion works. Current water use in the basin is discussed in relation to the volume of water diverted from the South Saskatchewan River. The paper concludes with a look at possible future directions for basin development which could require additional diverted water from the South Saskatchewan River.

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INTRODUCTION

The South Saskatchewan-Qu'Appelle River diversion is, as a point of technical fact, an intrabasin transfer rather than an interbasin diversion. Water is released from Lake Diefenbaker, on the South Saskatchewan River, through Qu'Appelle dam to the Qu'Appelle River. The Qu'Appelle is tributary to the Assiniboine River which is tributary to the Red River in Winnipeg. The Red River joins the Saskatchewan River in Lake Winnipeg and the circuit is complete for the diverted water (Figure 1).

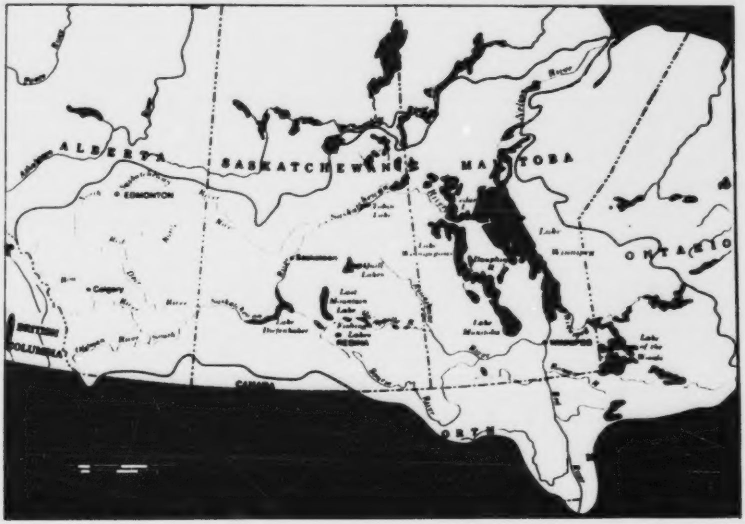
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
EDMONTON
Calgary
Saskatoon
REGINA
Lake Diefenbaker
Lake Manitoba
Lake Winnipeg
BRITISH COLUMBIA
CANADA

Figure 1: Map of Saskatchewan-Nelson Basin

The Qu'Appelle River originates out of a height of land less than 20 km southeast of the sharp northward bend (the Elbow) in the South Saskatchewan River (Figure 2) and flows eastward 770 km to join the Assiniboine River. The Qu'Appelle basin covers 51,000 km^2 and lies entirely in the geographical area known as the Saskatchewan Plain. The basin is predominantly a flat to gently undulating treeless plain sloping from an elevation of 600 m in the highest reaches, to 400 m at the confluence with the Assiniboine. Local relief generally doesn't exceed 5 m which makes the Qu'Appelle Valley and the valleys of its larger tributaries, striking topographical features by contrast.

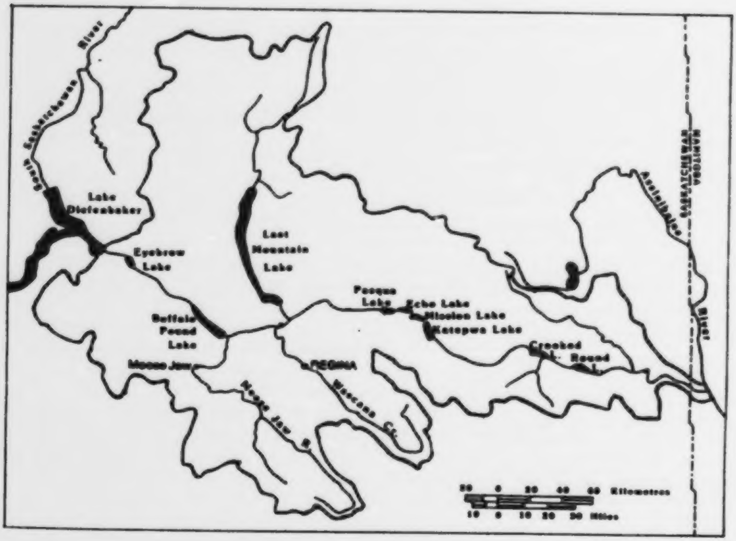
South Saskatchewan River
Lake Diefenbaker
Eyebrow Lake
Last Mountain Lake
Buffalo Pound Lake
Moose Jaw
Moose Jaw R.
REGINA
Wascana Cr.
Pasqua Lake
Echo Lake
Mission Lake
Katepwa Lake
Crooked L.
Round L.
Assiniboine River
SASKATCHEWAN
MANITOBA
20 0 20 40 60 Kilometres
10 0 10 20 30 Miles

Figure 2: Map of Qu'Appelle River Basin

History

The Qu'Appelle basin sits on two to three hundred metres of sediment, the product of four periods of glaciation. During the retreat of the last glacier, about 14,000 years ago, the South Saskatchewan River joined the Qu'Appelle near the Elbow of the South Saskatchewan River. They formed one meltwater channel carrying water from the Wisconsinian glacier eastward to Lake Agassis in Manitoba. Eventually, as the glacier receded further north, the meltwater was diverted at the Elbow to follow the route the South Saskatchewan River travels today. The Qu'Appelle was left as a deep valley, up to 180 metres in places, carrying much lower flows from local runoff. Erosion by wind and water over the several thousand years have partially filled the valley bottom and rounded the hills thus softening the contours as we see them now.

For centuries the valleys of the Qu'Appelle and its tributaries were a welcome refuge for man and beast. An ideal place to live with good hunting and fishing close at hand. Then came the fur traders to whom the river was a means of transportation. In the latter part of the last century the railroad became the mode of transportation and communities sprang up along the ribbon of steel. Settlers began to trickle into the region of the Qu'Appelle in the 1870's. By the 1880's considerable settlement had taken place along the valley and on the surrounding plains.

Commercial fishing in the Qu'Appelle lakes began in 1885 and continued until the 1930's when it was discontinued in favor of recreational fishing (PFRA, Hydrology Report #23, June, 1958). Control of the fishing lake levels was effected in 1888 with dams at the outlets of Echo and Katepwa lakes. A drought in 1889 caused farmers to better appreciate the value of stored water. There followed a flurry of small stockwater dam construction throughout the basin.

The first irrigation in the Craven to Highway #6 reach of the basin began sometime around 1890. Earth plugs were placed in the main channel, temporarily backing the water up onto the hay flats on the valley floor.

The earliest industrial use of Qu'Appelle water would have been directed toward railroad requirements. A subsequent industrial use was cooling water for the power plants of Regina and Moose Jaw.

The lakes of the Qu'Appelle provided the only local location for water based recreation for the centres of Regina and Moose Jaw. This led to the construction of the first control structure at Craven for the purpose of controlling lake levels on Last Mountain Lake. In 1935 the newly formed Prairie Farm Rehabilitation Administration (P.F.R.A., formed by the signing of the Prairie Farm Rehabilitation Act) received petitions to improve the control structures previously built and to construct another below Buffalo Pound Lake.

Municipal water supply for the growing centres of Regina and Moose Jaw was initially supplied locally, predominantly from ground water sources. Quite early in the development of these fast growing communities, however, it was apparent that local water supplies would not always be a sufficient source of supply. In 1911 the Provincial Water Rights Branch granted the cities of Regina and Moose Jaw a reservation to use 5.7 m^3/s (200 cfs) annually from the South Saskatchewan River (P.F.R.A., Hydrology Report #23, June 1958). That represents an annual commitment of 179,000 dam^3 (145,000 ac. ft.), which is approximately six times the amount drawn from the South Saskatchewan River to satisfy today's level of municipal use. Thus the seeds of a future diversion of water from the South Saskatchewan River to the Qu'Appelle were sown.

The Diversion Philosophy

The requirement of a future, supplemental municipal water supply for the cities of Regina and Moose Jaw led to the early recognition of the South Saskatchewan River as a possible source. That fact notwithstanding, the potential for diversion was an inevitable outcome of water resource development and long range planning. As early as 1859, explorer Henry Hind proposed the diversion of South Saskatchewan River water to the Qu'Appelle for irrigation and navigation. Hind proposed that the diversion be effected by building a dam on the South Saskatchewan River north of Elbow.

The design of the South Saskatchewan River Project could not have proceeded very far before it became obvious that another dam would be required to prevent the diversion of the entire flow of the South Saskatchewan River down the Qu'Appelle. The concept of the Qu'Appelle dam was conceived to forestall the river from reverting to its original alignment of some 14,000 years earlier. It follows that the design of the Qu'Appelle dam would incorporate some form of outlet structure to accommodate the possibility of diversion to the Qu'Appelle at some future date.

So it would seem that with or without the cities of Regina and Moose Jaw the diversion of water from the South Saskatchewan River to the Qu'Appelle would be dictated on a basic precept of good planning which is to keep the most options open at least cost.

Pump Diversion

Although farseeing individuals were aware of the future water supply requirements of Regina shortly after the turn of the century, little was done about it until 1948. The demand of expanding industry and population in the two cities was fast outgrowing the water supply available from local wells. Pipelines from Buffalo Pound Lake to the two centres appeared to be the only possible solution.

In May of 1950 the province received a guarantee from the federal government, responsible for interprovincial waters, that the water supply requirements of the cities of Regina and Moose Jaw would be supplied from the South Saskatchewan River (Proceedings of U of Regina Conference, February 27, 1981).

Studies were conducted with the involvement of the three levels of government. The outlet structure on Buffalo Pound Lake was reconstructed in 1952 providing an additional 0.60 m (2 feet) of storage in the lake. A system of pumps and canals was constructed to convey the water from the South Saskatchewan River to Buffalo Pound Lake.

Pumping to maintain storage levels in Buffalo Pound Lake began in a limited way in 1958 but actually began, in earnest, in 1959. Between 1958 and 1963 an average of 23,000 dam^3 (18,600 ac. ft.) (P.F.R.A., Hydrology Reports 29 and 29A to 29E, 1959-1964) was pumped from the South Saskatchewan annually. During this period two problems became evident. First, conveyance losses from the pump site to the lake were high. This included high evaporation losses in Eyebrow Lake, upstream of Buffalo Pound Lake. Second problem, the high quality of the pumped water deteriorated significantly on passing through Eyebrow Lake (P.F.R.A., Hydrology Report #29, 1959).

The solution was to construct a canal allowing the flow to bypass Eyebrow Lake. This indirectly led to a second use of diverted water, the Nisku waterfowl project established in Eyebrow Lake. Diversion water can now be released from the bypass canal to any one of four cells in the marshy lake to maintain levels for the waterfowl habitat. The quantity of water diverted to Eyebrow Lake annually is relatively small and is a function of the volume of spring runoff and the amount and timing of summer rainfall.

Gravity Diversion - Qu'Appelle Dam

On May 27, 1959, Prime Minister Diefenbaker officiated at the ground-breaking ceremonies at the site chosen for the dam on the South Saskatchewan River. The construction agreement was signed in 1958 and contained a clause transferring to the province the 1950 federal commitment to supply the municipal water requirements of Regina and Moose Jaw from the South Saskatchewan River. Although the South Saskatchewan River Project was primarily intended for irrigation, hydro electric development, and regulation of flows, the implementation of the 1958 agreement specifically provided for the exchange of the cumbersome pump scheme for a gravity diversion. Under the terms of the 1958 South Saskatchewan River Agreement an annual allocation of 92,500 dam^3 (75,000 ac. ft.) was licenced to the Qu'Appelle.

Construction of the Qu'Appelle dam began in October of 1963. The site finally chosen was known as the Summit Site, located on the drainage divide between the Qu'Appelle basin and the South Saskatchewan River. Completion of the works took place in November 1967.

The capacity of the outlet structure in the Qu'Appelle dam was designed considerably greater than that of the pump system it was to replace. Sizing of the design discharge capacity of the outlet works was based on studies of projected water demands within the Qu'Appelle basin. The proportion of that demand that could not be supplied by water from within the Qu'Appelle basin would be a measure of the releases that would be required from the Qu'Appelle dam.

The design of the outlet works was based on a minimum flow of 36.8 m^3/s (1,300 cfs) at a reservoir elevation of 545.6 m (1,790 feet) (P.F.R.A., The Design and Construction of Gardiner dam, 1980). That is the average diversion flow necessary to satisfy projected demands for the year 2000. The reservoir elevation is the minimum likely to occur at the time of maximum diversion. At the reservoir full supply level of 556.9 m (1,827 feet) the discharge capacity of the Qu'Appelle outlet structure is 68 m^3/s (2,400 cfs).

Diversion Operation

The Qu'Appelle River system today spans almost two thirds of the width of the Province, contains nine lakes and can be regulated at nine control structures. The Qu'Appelle Operation Board was established in 1971 and developed operation procedures designed to provide maximum overall benefit for all purposes including municipal, industrial, agricultural and recreation uses as well as pollution abatement and flood control (Banga, A.B., and Thiele, L., December 1986). An additional consideration is Saskatchewan's commitment to Manitoba under the 1969 Master Agreement on Apportionment*. Operation of the system includes operation of the Qu'Appelle dam outlet structure to release water to the Qu'Appelle.

Earlier this year, in April 1987, the Board was dissolved and reorganized as the Qu'Appelle Operation Committee. The reorganization was required for administrative reasons, but the membership and purpose essentially remain as before. The purpose of the Operation Committee is to operate the Qu'Appelle River system, including releases from Lake Diefenbaker, impartially to the mutual benefit of all users. Membership on the Committee is from the following federal and provincial agencies:

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* The Master Agreement on Apportionment, signed in 1969, is administered by the Prairie Provinces Water Board and, in the case of the Qu'Appelle River, assures Manitoba the right to 50% of the natural flow at the provincial boundary.

- Prairie Farm Rehabilitation Administration, Agriculture Canada,
- Saskatchewan Water Corporation,
- Saskatchewan Environment and Public Safety,
- Saskatchewan Parks, Recreation and Culture.

The Operation Committee meets at various times of the year as requests for control dictate. They also meet at specific times of the year as flow conditions dictate such as in the spring, prior to runoff, in the late spring, after runoff is complete, and in the late summer. Based on past and present flows as well as streamflow forecasts, an operating plan is formulated for the pending period. Recommendations of the Committee are turned over to Saskatchewan Water Corporation to implement. Operation of Qu'Appelle dam is the responsibility of the P.F.R.A., while the outlet of Buffalo Pound Lake is controlled by Saskatchewan Agriculture. Both agencies cooperate with the recommendations of the Operation Committee as conveyed to them by Saskatchewan Water Corporation.

Today water is imported from Lake Diefenbaker to the Qu'Appelle River system to meet various water requirements such as:

- Regina and Moose Jaw city water supplies;
- industrial use by Kalium Chemicals mine at Belle Plaine (pumped directly from Buffalo Pound Lake);
- Nisku waterfowl project on Eyebrow Lake;
- fresh water to maintain lake levels during the summer months; and
- maintenance of streamflow for irrigation and stockwatering demands.

Releases through the Qu'Appelle River dam are made by adjusting the control gates to settings obtained from rating curves which relate discharge flows to lake levels and gate openings. Although the structure was designed to release up to 68 m^3/s (2,400 cfs) to meet possible future domestic, industrial, and irrigation demands within the Qu'Appelle, releases to date have been limited to 11 m^3/s (400 cfs). The restriction is due to the limited channel capacity in the upper Qu'Appelle. Often the conveyance capacity is further reduced by weed growth during the summer months. Reductions of as much as 50% to 75% can occur, severely limiting the diversion rate.

Present Perspective on Basin Water Use

A total of 1,561 surface water projects within the Qu'Appelle basin are registered with the Water Rights Branch, Saskatchewan Water Corporation, to date. Of those, 90% have been authorized, amounting to a total annual allocation of 73,700 dam^3 (60,000 ac. ft.).* Water is allocated predominantly for such uses as municipal, domestic, irrigation and industrial. The amount allocated to use in the basin is not a measure of mainstem water use because a considerable amount of water is allocated to users along the many tributaries as well as users elsewhere in the basin. Nor is the figure a measure of the volume of water actually used annually. It does, however, give an appreciation of the level of water demand within the basin. The annual allocation is even more significant when compared to Saskatchewan's 50% share (under the 1969 Master Agreement on Apportionment) of the average annual natural flow at the provincial boundary, 125,000 dam^3 (101,500 ac. ft.).**

It should be noted that the municipal, surface water requirements of Regina and Moose Jaw are not included in the 73,700 dam^3 of authorized water use in the basin. Regina and Moose Jaw municipal surface water is a water right drawn on the South Saskatchewan River Basin. During the period 1980 to 1983 the average annual quantity pumped from Buffalo Pound to supply the cities of Regina and Moose Jaw was 30,000 dam^3 (24,000 ac. ft.) (Banga, A. B., and Thiele, L., December 1986). An additional 4,200 dam^3 (3,400 ac. ft.) were piped from Buffalo Pound Lake to the Kalium Chemicals solution mine at Belle Plaine.

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* Information supplied through the courtesy of the Water Rights Branch, Saskatchewan Water Corporation.

** Natural flow figures for the Qu'Appelle River at the provincial boundary for the period 1956-1981 supplied in unpublished form through the courtesy of the Prairie Provinces Water Board. The average annual natural flow for the period is 250,000 dam^3 (203,000 ac. ft.) of which Saskatchewan's share is 50% or 125,000 dam^3 (101,500 ac. ft.).

The greatest single user of water in the Qu'Appelle basin is the atmosphere. The average annual net evaporation from the nine Qu'Appelle lakes alone amounts to 140,000 dam^3 (113,000 ac. ft.)*, more than Saskatchewan's share of the average annual natural flow at the Manitoba border. The maximum net evaporation loss from the Qu'Appelle lakes occurred in 1980 with 205,000 dam^3 (253,000 ac. ft.) going up in vapor.

Other basin water uses are recreation and wildlife uses. Recreation requires maintaining water levels in the lakes during the summer months. Wildlife use is largely made up of Ducks Unlimited projects as well as the Nisku project in Eyebrow Lake.

Diversion Releases

Annual releases from Qu'Appelle dam between 1967 and 1983 have averaged 58,000 dam^3 (47,000 ac. ft.). The lowest quantity diverted was 19,000 dam^3 (15,000 ac. ft.) in 1974. 1974 was a record runoff year for the Qu'Appelle basin with major flooding at many points throughout the basin. The largest quantity released to the Qu'Appelle was 142,000 dam^3 (115,000 ac. ft.) during the drought year of 1981. Much of this water was routed through the system to maintain freshwater flow through the lakes.

Of the water released from Qu'Appelle dam, 30,000 dam^3 (24,000 ac. ft.), on the average, goes to supply the annual municipal needs of Regina and Moose Jaw. Another 4,200 dam^3 (3,400 ac. ft.) is pumped from Buffalo Pound Lake to Kalium Chemicals. The Nisku waterfowl project in Eyebrow Lake takes an additional average draft of 4,000 dam^3 (3,200 ac. ft.). The average total annual demand of the three direct users of diversion water is 38,200 dam^3 (31,000 ac. ft.), which is about two-thirds of the annual average quantity of water diverted to the Qu'Appelle from the South Saskatchewan River.

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* Based on calculations using Saskatchewan-Nelson Basin Board net evaporation figures updated to cover the period 1911-1984. This information was made available in, as yet, unpublished form through the courtesy of the Hydrology Division of P.F.R.A.

Future Prospects

Obviously as time goes on, developments in the Qu'Appelle basin will require increased quantities of water. Regina and Moose Jaw are not going to go away. They will continue to grow and so will their demand for water. But let's look beyond those ever growing demands to the potential for increased diversion of water.

Three proposals are to be described here and are all well documented in Appendix 3 of the 1972 Report of the Saskatchewan-Nelson Basin Board. All three schemes would require an enlarged outlet structure in Qu'Appelle dam as well as a much improved conveyance capacity in the Qu'Appelle River channel.

The first proposal is the Lake Diefenbaker to Upper Assiniboine River diversion. Releases from Qu'Appelle dam would be carried by the Qu'Appelle to Valeport where a pump station would facilitate the raising the water 65.5 m (215 ft.) to a canal. The water would then flow under the influence of gravity, north along highway 20 and then east, passing south of the Quill Lakes. After passing through a number of drop structures, lowering the water some 56 m (184 ft.), the flow would join the Assiniboine River entering the reservoir of the proposed Kamsack dam.

The second proposal is known as the Qu'Appelle River Conveyance Channel. This proposal simply requires increasing the conveyance capacity of the Qu'Appelle River channel to carry the proposed design flows. Four flow volumes have been suggested between 14.2 m^3/s (500 cfs) and the 1:50 flood flow, which varies from reach to reach. Besides the channel conveyance improvements a number of drop structures would be required as well. Finally, Victor dam would be built on the Qu'Appelle River in Saskatchewan a few miles upstream of the Manitoba boundary.

The third glimpse into possible future developments is known as the Qu'Appelle River to Souris River diversion. A pump station would be located below the Craven Control structure. The diverted water would be lifted 119 m (380 ft.) to a canal which would convey the water over 145 km (90 mi.) in a southeasterly direction to flow into the proposed Rafferty Reservoir. Turnouts along the route would allow releases of diversion water to the proposed Boggy Creek reservoir, to the Wascana Creek immediately upstream of Regina, to Wascana Creek above the proposed Sedley Reservoir and to Moose Jaw Creek via a canal.

At Glen Ewen the water can once again be pumplifted a further 18 m (59 ft.) to a canal carrying it 29 km (18 mi) to enter a proposed Antler River reservoir. The flow would pass down the Antler River into Manitoba, bypassing a short reach into North Dakota, ending up in a proposed reservoir behind Coulter dam just above the confluence of the Antler and Souris Rivers.

In brief, those are the possible future diversion developments which will impact upon the Saskatchewan-Qu'Appelle diversion. The concept of such megaprojects as the three proposals just described makes todays modest diversion volumes pale by comparison. Water is a valuable commodity in the southern prairies and becoming more valuable all the time. The time may come when the economic realities may well see one or more of those farsighted proposals come into fruition. The report of the study now in progress under the Canada-Saskatchewan South Saskatchewan River Basin Study Agreement will give a clearer picture of future directions for water resource planning in the South Saskatchewan River Basin as well as diversions from the basin.

Conclusion

The South Saskatchewan-Qu'Appelle River diversion has not begun to realize its potential as a water resource alternative. In the almost 20 years of operation the volume of water diverted is slightly more than one half of one percent of the natural flow of the South Saskatchewan River entering the Province of Saskatchewan. An insignificant quantity, well within the confidence band surrounding the best hydrometric records available.

Considerable more water resource development could take place within the Qu'Appelle basin before the diversion quantities would become appreciable. As previously described, there are some very ambitious water resource schemes on the drawing board which would, if implemented, use large quantities of diversion water and have very far reaching effects on the environment and economy of southeastern Saskatchewan as well as Manitoba.

The purpose of this paper is not to promote greater diversion development on the premise that if a little is good, more will be better. However, increased diversion does appear to be inevitable. A Saskatchewan Environment report (Water Management in Saskatchewan, Volume 1, September 1980) states, "The concept (Interbasin transfer from the South Saskatchewan River to the Qu'Appelle River) will become more and more necessary with time. Consideration must be given to the two major costs associated with water transfer, the cost of benefits foregone on the Saskatchewan River system, and the cost to manage the water once it enters the Qu'Appelle." It is to be hoped that before any large scale diversion projects are launched, with possibly irreversible consequences, water resource planners avail themselves of the lessons to be gained by past experience and consider more than economics alone.

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INTERBASIN TRANSFERS FOR AGRICULTURE IN THE CANADIAN PRAIRIES: THE NON-STRUCTURAL FACTORS

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ABSTRACT

In the Prairie Provinces, there was little opposition to interbasin transfer for irrigation in the early part of this century and local transfers were part of the development picture. Most were in Alberta where the physical geography was most favourable. There was over-development by companies relative to farmers' capacities to pay for it and government support was needed for continued operation. Government support for irrigation grew after World War II, partly in acceptance of claims that secondary benefits in regional development were valid bases for support. Government subsidies are now proportionately larger in Canada than in the United States.

Government support for interbasin transfer was strong in research and in promotion in the late 1960's, partly in anticipation that water export would soon be important. By 1970, export proposals had earned widespread condemnation and most of the proposals for transfer within Canada were soon discarded also. The major reasons were economic - there was little basis for the subsidies needed - but environmental, legal, regional interest and other reasons for transfer avoidance were marshalled and it became politically expedient for governments to issue policy statements against transfer.

In recent years, there has been some renewal of interest in transfers. It is not yet politically wise to promote them, except in the regions that might benefit from transfer payments, but opposition and support are both weak and open to change with adequate incentives.

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Massive transfer with massive subsidization cannot attract widespread support but smaller scale transfers with small subsidies might be acceptable. Economic viability, as in transfer for hydro development, is probably the key and it is very unlikely for agricultural transfers in the near future. In the long run, with CO_2 warming, changing agricultural markets and other factors we might anticipate the acceptance of transfer as one of many options in water development.

Most of the studies of water transfer for agriculture in the Prairies have been on the alternative structural means and routes and there have been comparatively few on the many non-structural factors that affect the viability of the projects. As Dean Marts, University of Washington (1984) said "Large inter-regional transfer of water is an idea that won't go away, but whose time refuses to come -- the inhibiting factors have always been strong -- they are growing stronger over time, so that whatever prospects once existed are fading". The inhibiting factors for large and small transfers for agriculture are largely non-structural. I'll review some of the highlights relative to past, present and future transfers in the Prairies.

Many of the irrigation projects in the Prairies employ water that has crossed basin and sub-basin boundaries. In Alberta, the Bow River Basin is a major source of transfers with almost half of the flow to the Western Irrigation District and over 70% of the flow to the Eastern Irrigation District, serving areas (including return flow) on the Red Deer Basin side of the divide; and with almost one quarter of the flow to the Bow River Project, all of the Highwood to Little Bow Diversion and some flow from Stimson to Willow Creek serving areas on the Oldman Basin side of the divide. A substantial part of the St. Mary River flow is diverted in Montana across a continental divide into the Milk River Basin, (a part of the Missouri - Mississippi Basin) and this added flow passes down the Milk River channel in Southern Alberta. Flow from the Waterton and Belly Rivers is transferred eastward into the St. Mary River. Some of this flows beyond the St. Mary and Oldman Basin divide to internal drainage basins (Lake Pakowki) and the Milk River Basin (Laycock 1980; Quinn 1981; Canada West Foundation 1982; Pearse et al. 1985). William Pearce, who had contributed greatly to C.P.R. project development before World War I, had proposed other projects involving North Saskatchewan and Red Deer River water being transferred eastward into Eastern Alberta and Saskatchewan (Mitchner 1966, 1971). In Saskatchewan, the transfer volumes have been smaller; including from the South Saskatchewan River at Meridian Dam at the Qu'Appelle River, both way transfers from Battle Creek and the Frenchman River at Cypress Lake, and small transfers from Swift Current Creek into small basins to the east. The early transfers were largely in Alberta, in part because of favourable topographic patterns: the rivers and streams near the foothills - plains margin were not deeply incised into the plain (as they were farther east) and diversion was easy. The numerous south-east trending pro-glacial spillway channels were excellent for both storage and diversion. Many of the divides were relatively flat and could be irrigated from either side.

Most of these transfer programs were developed before and just after World War I in a rapidly expanding economy in which little thought was given to environmental or other reasons for limiting transfer. The comparative costs of alternative supplies dominated decision making. Most of the transfers were inter-tributary within larger basins but the environmental problems relating to underfit and overfit streams were the same.

Most irrigation delivery systems, including transfers, were built very cheaply because the returns from land sales and production based on irrigation were too meagre to cover more expensive systems. As noted by Smith (1978), corporations such as C.P.R. (Hedges 1939; Mitchner 1966; 1971) and the Canada Land and Irrigation Co. (Stotyn 1982) failed to obtain substantial returns on their investments and they released their holdings to farmers districts and the government at a loss between the mid 1930's and early 1950's. Locally organized irrigation districts also needed provincial funding assistance and, in some cases, direct management.

The "Government Phase" (Smith 1978; Topham 1982) of irrigation development, after World War II, was in part a rescue operation to avoid a collapse of some of the irrigation projects (some not yet districts), and maintenance and improvement of the water delivery systems was a major part of government involvement. Major expansion was undertaken with the Government of Canada paying for the major storage and diversion and the provincial governments paying for district delivery systems, and settlement.

Formulas for payment, based upon benefit allocation, were devised - e.g. Rogers, Manning & Grubb (1966) suggested that the direct and indirect benefits from keeping the Easter Irrigation District from failing were such that rehabilitation project costs should be allocated 11% to the irrigation farmers, 22% to other local (municipal) sources, 32% to the province and 35% to the nation[2]. It was recognized that the municipality had little capacity to pay and this portion was later re-allocated leaving the farmers with 14%, the province with 42% and the nation with 44%. When Canada's interest in Alberta irrigation projects was transferred to the province in 1973, the provincial commitment was accepted as 86%. The leap from a salvage operation formula in which the choice was one of maintaining or abandoning an existing irrigation project rather than extending it or establishing a new one, was political. It was partly based on American reclamation policies of regional development and was tied to drought-area farmer and soldier re-settlement after World War II. The major political parties in the Prairie Provinces and the Federal Government supported these programs.

There is widespread promotion of subsidies for irrigation, usually in the form of structural works, paid for by governments on the assumption that the wider economy will gain from the secondary and tertiary benefits (Alberta Irrigation Projects Association 1984; Kulsheshtha et al. 1985). Most economists point out, however, that there are similar secondary and tertiary benefits from similar investment elsewhere and although some areas, individuals, and engineering firms may benefit from these transfer payments, they do so at the expense of other sectors of the economy (Howe 1971; Kelso et al. 1973; Treasury Board of Canada 1976; Veeman 1978 and 1985).

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[2] Alternative allocations were also outlined.

The U.S. National Water Commission (1973) in commenting on interbasin transfer concluded that "the direct beneficiaries of a project pay the full costs ... which include not only the construction, operation and maintenance costs plus interest at market rates prevailing at the time of construction but also ... the net losses suffered by the area of origin because of the export of water. Even for benefits such as fish and game, recreation and scenic beauty, the States in which the benefits are generated should be required to pay their share of the costs" (p. 328). This was in part a reaction to the activities of the Bureau of Reclamation and the Corps of Engineers which had provided massive government subsidies in some irrigation projects and were studying larger transfer opportunities. Other reactions to the massive spending programs are outlined well in recent books such as "Cadillac Desert" by Marc Reisner (1986) and "Rivers of Empire" by Donald Worster (1985). It is probable that the subsidy level in Canada is now greater per unit area irrigated than in the United States. This is largely because over 80% of Prairie irrigation is in irrigation districts with subsidized storage and diversion of surface streamflow. In contrast, well over three quarters of the American acreage is in private, largely family, projects based upon groundwater and small scale diversion (Frederick & Hanson 1982).

It is of interest also that Canada has a greater volume of water transfer than the United States and the U.S.S.R. combined (Quinn 1981) but, even with subsidies, the irrigation oriented portion is less than 2%. Hydro power production is the greatest basis for transfer and the prices of this primary product have resulted in very favourable cost/benefit ratios without the inclusion of secondary and tertiary benefits - although the allowances for environmental and social costs have often been small. If transfer is profitable, the environmental and other objections can apparently be overcome. If transfer requires subsidies, these objections can become major reasons for delay and non-development.

In physical terms, interbasin transfers can be the largest and most dependable sources of water for the southern plains. It is also a costly alternative source and we should be aware of alternatives to it in economic, environmental and political terms as well as in timing and scale before we decide that we should proceed with development.

The physical supply options have been discussed in numerous studies (e.g. Saskatchewan - Nelson Basin Board 1972) and summaries (e.g. Laycock 1976, 1979; Engelbert and Scheuring 1984). In summary, they involve 1) better storage from wet to dry seasons, 2) better storage from wet to dry years, 3) better and conjunctive use of ground water, 4) better watershed management in both the Eastern Slopes and the Plains including rain gathering and snow management and recognition of the effects of land use change such as urbanization, 5) weather modification - largely in mountain headwater areas, and 6) desalination of brackish groundwater. It is evident that the supply improvement potential for irrigation, other than by transfer, is relatively small. The better storage sites have been developed relative to dry year supply and wet to dry year storage can be expensive. Despite this assessment, irrigation area could probably be doubled with existing in-basin supplies if demands and subsidies are large enough (Environment Council of Alberta 1979; Canada West Foundtion 1982; Prairie Provinces Water Board 1982; Alberta Environment 1984).

The demand side of management has at least as great a potential contribution to irrigation acreage expansion. All of these could affect the timing and scale of interbasin transfers. Some of the categories involve both supply and better management: 7) Evaporation and transpiration loss suppression. There may be some potential for dugout supply stretching and greenhouse development but the irrigation scale will be small.

8) Re-use and re-cycling of urban, industrial and other waste flow. There is some potential - e.g. east of Calgary - but quality and location limitations are large. Storm water runoff increases with urbanization have been large and they more than balance urban consumptive use (Laycock and MacKenzie 1984) thus more water is available for irrigation and other uses than is usually reported.

9) Better conjunctive use of water from multiple sources. Irrigation in the Prairies is, to a large degree, supplemental to precipitation yet many irrigators regard rain and snow as nuisance additions that disrupt irrigation scheduling. More could be done in rain and snow use and management to reduce irrigation demand. There is little incentive when water supply subsidies are so large. Better integration of supply sources, rather than subsidized development of only surface storage and delivery, could help.

10) Greater efficiency in the use of irrigation water. The overall irrigation efficiency in the Oldman Basin between 1968 and 1974 was estimated to be about 31% (Maasland 1978; E.C.A. 1979 p.95). This is the product of reservoir storage efficiency times delivery efficiency times farm efficiency. Reservoir storage efficiency is declining as more reservoirs are added but losses are still far below the storage additions to available supply. Delivery efficiency has been improved greatly but at considerable expense in the canal rehabilitation (lining etc.) programs of recent years. Farm efficiency has been improved by the much more widespread use of sprinklers. Overall efficiency is probably still in the 40-50% range and the trend is still upward. This trend could be steepened by higher prices, metering, closer monitoring and by other means and we could conceivably reach the 60-70% efficiency level - but only at increased expense. We should also recognize that the return flow

part of the inefficiency noted is available for use downstream and that some waste within districts may contribute to habitat enhancement and aesthetic environment improvement. However, some of the wastes are related to salinization and erosion problems and should be kept to a minimum. With greater efficiency, the irrigable area might be expanded substantially and/or production per unit area might be increased.

11) Priorities in use and cut-back in the drier years. Cutting back in the drier years is very unpopular because the irrigation product markets are best in these years. Water demands are much greater in these years - e.g. 18 to 24 inches of apparent consumptive use compared with less than half of this amount in average years (Canada West Foundation 1982). We gauge our irrigable land potential on dry year supply and demand patterns and try hard at whatever expense to supplement dry year supply. In most irrigated areas of the world, irrigation is extended to close to average year supply and demand (in the South Platte basin below Denver the water rights allocation is to over 280% of average flow) and farmers are obliged to do with less in dry years. Near Davis, California, in the Putah Creek District, farmers know their water quotas from Berryessa Reservoir in spring and tend to grow cereal grains and pasture in low flow years and alfalfa, tomatoes, rice etc. in high flow years. Acreage and crop variation with supply is normal - not as in Alberta where the greatest acreage and the most water demanding crops will be stressed in dry years. Quotas, priorities and other controls could be based upon supply expectations, crop proposals, time of operator or land used within the district (recent additions based on pumping for "above the canal" use might have lower priority), farm area (the smaller farms have priority over the larger), and price of water. Cutting back in the very dry years (e.g. one in ten) could be very much cheaper than provision of year to year storage facilities or water transfer, perhaps to the degree that the farmers involved could be paid not to grow crops on some of their lands. This would highlight the subsidies now present.

12) Relocate certain irrigated crops elsewhere in the region - either with supplemental irrigation where water is more readily available or with dryland farming. Crops such as wheat that can be grown more cheaply with dryland farming should not be subsidized. Perhaps a shift in subsidy and quota protection patterns, away from providing very low cost water to irrigation farmers, toward quota protection for sugar beet production (the United States has both) would help irrigation farmers more than our present policies.

Many political, social, legal, environmental and other aspects are involved in decision making relating to these and other demand side issues. Irrigation isn't a wholly separate part of the Prairie economy and it must be related to the state of the economy of each province and the country as a whole.

In the early years of transfer development for irrigation there was little opposition relating to declining environmental quality. Most people in irrigation areas were convinced that most environments were improved - "turning the desert green" was a laudable objective. Wildlife benefitted from better water supply, better forage and better shelter, especially in the drier years. Waterfowl use of reservoirs and ditches and of Ducks Unlimited facilities (later) resulted in increased waterfowl populations and better migration. Pheasants flourished, partly because canal leakage contributed to improved habitat. In more recent years, some of the habitat have deteriorated with better lining of canals and more efficient delivery systems - there is less water for weed, shrub and tree growth. Erosion damage was local - e.g. gully erosion on ditches carrying return flow, especially without drop-structures to the Red Deer River (the badlands were being extended) and slumping in the Little Bow valley. Salinization has been widespread but canal lining, sprinkling and other measures are helping to limit it. Valley ecosystems have been flooded by reservoirs - but reservoir fishing has become significant. Environments have changed and preservationists might object but the relatively small scale of development and the lack of widespread abrupt change have meant that apparent damage has been limited and environmental enhancement, however inadvertent, has been roughly compensating.

Massive transfers have been proposed - in Alberta's P.R.I.M.E. program (Bailey 1969; Alberta Department of Agriculture 1969), in the Saskatchewan-Nelson Basin Board (1972) study, in the Alberta Water Advisory Committee (1981) report and in a number of water export schemes. Environmental considerations have been included in the Saskatchewan-Nelson study and to a lesser degree in some others but it is apparent that the impacts would be very large. Attempts to keep damage to a minimum and to provide for at least compensating enhancement for damage done will be costly but development on any other basis is no longer politically acceptable.

Lesser scale sequential transfers, only after cheaper alternatives have been employed and well defined demands have been demonstrated, will probably be more viable than the massive transfers noted. It is probable that some transfers will be cheaper and more dependable than provision of extra storage and it is also probable that environmental quality will suffer less and may gain more than might be true for either large scale transfers or added storage. To test this, Brian Gregg conducted a M.Sc. thesis study of possible transfer from the Clearwater River to the Red Deer River (from the North Saskatchewan to the South Saskatchewan Basin). In this study, a number of alternative ways of transferring up to 150,000 dam^3 per year (up to 30% of Clearwater flows) were reviewed. This would be sufficient to support over 32,000 hectares of irrigation on a dry year irrigation duty of 457 mm (18 inches). This area is equal to a 3 to 4 year average growth in irrigation in Alberta in the last 20 years and, with storage of part of the wetter years transfer flows for dry year use, the needs of possibly twice this area might be met.

The Clearwater River is now flowing with little channel incision on the north flank of a pro-glacial fan delta and there is some natural transfer by groundwater flow and occasional flood overflow to eastern parts of the fan that are tributary to the Red Deer River (via Stauffer Creek and the Raven River). A number of alternative means and routes of transfer are available and some of these could be developed with little environmental damage, more than compensating environmental enhancement, and at little additional cost relative to environmentally damaging alternatives. I have described these at meetings of the Alberta Fish and Game and Alberta Fly Fisherman's Associations and the reactions have been positive. There is little doubt that this supply would be available at lower cost than an equivalent amount from wet to dry year storage. It could be used in the Red Deer Basin or it could be permitted to flow unused into Saskatchewan to meet part of Alberta's downstream commitment and enabling Alberta to use larger portions of the Bow and Oldman flow in these years.

An important feature of water supply for irrigation in Alberta is that there is abundant water in average and wet years and only very dry year flow will be in short supply in the near future. It would be far cheaper to pump water from the North Saskatchewan River over the low divide near Rocky Mountain House (just North of the Clearwater division) in these dry years than to a) build dams for such diversion or b) provide extra storage and supply augmentation in the South Saskatchewan Basin. The most viable option is to cut back on irrigation in dry years but pumping could be more viable politically. If and when much larger diversions are needed, then larger structures may be built - but meanwhile there would be no carrying charge on hundreds of millions of dollars of capital investment and the needs of irrigators could still be met. At some point in time a replacement supply may be needed for North Saskatchewan flow and this could be met by diversion from southern tributaries of the Athabasca River - e.g. the McLeod, Pembina and La Biche Rivers. Eventually, sequential development could involve the main stem of the Athabasca (dry year pumping initially?) and perhaps the Peace River tributaries and main stream - but not until warranted by demand. Assurance of future supply or replacement supply can be an important basis for planning and for deflection of criticism concerning loss of supply for future basin needs. The smaller scale and deferred developments could be more acceptable to environmentalists, especially if the costs of keeping damage to a minimum and of providing for compensating enhancement are included.

Much of the interest in the Prairies in water transfers in the 1960's was related to proposals for water export (Laycock 1971; Quinn 1973). In the N.A.W.A.P.A. (North American Water and Power Alliance) scheme (Parsons 1964; U.S. Senate 1966; Moss 1967 a & b), widespread irrigation in the Prairies was to be a supplement to massive transfer from Northwestern Canada and Alaska to the American Southwest. Canadian observers such as Magnusson (1967-69) , Kuiper (1966), and Tinney (1967) proposed export programs in which Canadian irrigation development would benefit from the economies of scale. The Alberta PRIME program (Bailey 1969) and the Saskatchewan-Nelson Basin Board study (1972) were officially not export oriented but thoughts of export revenue were not entirely absent - at least until about 1970 when the negative reactions to NAWAPA and other schemes became dominant.

Canadian opposition to water export was largely oriented to NAWAPA. It was soon recognized that the irrigation benefits might be obtained more cheaply by other means and that the navigation benefits in largely ice-bound northern areas were high-cost illusions of limited value. Environmental costs would be massive with few compensating benefits. The flooding of Canadian valleys (including Whitehorse and Prince George) and the cutting of East-west transportation routes to provide storage and head for southern deliveries would be high costs to Canadians. The allocation of much of the hydro power resource of the Canadian Northwest to pumping water southward, with partial recovery with descent in the American Southwest to benefit that region, was not acceptable. It was part of the assumption that the American dominated "Alliance" would control regional resource development, and American know-how would bring development benefits to Canada. It was recognized that the agricultural market could not obtain sufficient primary benefit to pay for the scheme thus it was assumed that massive subsidies by the Canadian and American governments would be provided because of the secondary and tertiary benefits derived from this development.

If agriculture could have provided enough benefits to cover the massive costs of transfer development plus environmental and opportunity costs, it is possible that major export transfers might have been undertaken. The benefit/cost ratios would probably have been no better than 0.2:1 for the best schemes with NAWAPA closer to 0.02:1 thus massive subsidies would have been required. Frederick and Hanson (1982) identified subsidy levels in Bureau of Reclamation projects in this range but nothing close to the export proposals in scale. In the years since 1970, the capacity of agriculture to pay for transfer has declined because produce prices have not kept up with inflation and the prices for engineering structures and services, energy and borrowed money (interest rates) have risen dramatically (Engelbert & Scheuring 1982). Support for massive transfers has dwindled with rising opposition by environmentalists, regions of origin and, perhaps most decisively, objections to the massive subsidies that would be needed.

Water export is still a possibility because state and federal governments in the United States, convinced that water is the key to economic growth, may be willing to provide subsidies if political pressures are strong enough. This conviction may be reinforced by artificially high water prices (including subsidies). The costs of water rights transfers, litigation, inter-state transfer (despite some recent improvement), waiting because of conflicting claims, political pressures to support traditional agricultural users, and growing environmental and social (e.g. Indian rights) claims and designated uses (e.g. wild rivers) have made "new" uncommitted water very attractive. Water qualities are continuing to deteriorate in many areas and the costs of clean-up are growing. "Pure" Canadian waters could command premium prices.

Climatic changes relating to increasing CO_2 and other "greenhouse gases" in the atmosphere, may have major impacts. The EPA (1984) projections for 50 to 100 years from now are for warmer conditions (3-5°C) in most areas and drier conditions in most parts of the United States - e.g. for the High Plains - Ogallala region 9% less precipitation, 9% more evapotranspiration and 26% less runoff. The political pressure for imports may be strong there and in the Great Lakes region, and Canada may be asked for water, perhaps even for Canadian subsidies for the development impacts upon our economy. If the prices are high enough to cover capital and operating costs, environmental and opportunity costs, and a profit, we might negotiate terms that do not involve specific water rights, that are flexible enough to cover inflation and permit gradual withdrawal if either side wishes. Water export must be negotiated on its merits. It must not be a pawn in a larger trade package that might rigidly commit us to an undervalued waste of our resources.

The EPA and other projections are for even greater climatic changes in Canada than in the United States (EPA 1984; Kates et al. 1985). In 50 to 100 years the Western Prairies will have 15% more precipitation, 22% more evapotranspiration and 14% more runoff to accompany a 34% increase in mountain runoff and a growing season that is 33 days longer. The eastern Prairies will have 11% more precipitation, 14% more evapotranspiration , 2% less runoff, and a 28 day longer growing season. The greater winter and spring precipitation followed by drier summers and falls in the Western Prairies could be good for changes from spring to winter wheat in many areas and for significant irrigation expansion. The seasonal changes in the Eastern Prairies would be less striking but irrigation could again be expanded substantially. The transfer opportunities with and without export could be large. The potential for error in these projections is also large but there is a basis for cautious optimism concerning the future agricultural climate and the water supply for it.

The political climate for water transfer is ever changing. The stress upon development in our economy has been modified less by environmental and other concerns than in most parts of North America (Ingram 1972). It is probable that environmental opposition to transfer, aside from that by some preservationists, will not be strong or united if smaller scale projects, with provision for keeping damage to a minimum and for at least compensating enhancement, are predominant. The farm block of voters is a declining part of the electorate and it is less united in support of irrigation expenditure than in the past. Dryland farmers and even some in irrigation are objecting to the free spending on irrigation structures (Edmonton Journal, May 9, 1987 p. C1) of the recent past. In the north, opposition to transfer of water from Northern to

Southern Alberta is still weak but the Northern Alberta Development Council is pressing the Alberta Government for an unequivocal statement on it's policy on diversion of water from northern rivers. If hydro development on the Slave River is anticipated, opposition to transfer could grow rapidly. This opportunity cost for transfer would not be so large that compensating benefit packages could not be provided by the Alberta government. In Alberta, both support and opposition to transfer are weak and, if subsidies were modest, there would be little outcry. If subsidy levels for a massive transfer proposal were expected to be large, opposition would grow rapidly and it is doubtful that any part would risk offering support even in prosperous times. At present, transfer support on more than a modest level is unlikely. We will probably confine development to levels that involve a bit more storage of existing basin supplies with a minimum of planning for the future. The recent report of the Alberta Water Resources Commission (1986), despite strong past support for transfer by the Commission chairman, contains almost nothing on transfer.

In the future if markets for irrigation products (now increasingly oriented to beef) improve and climates for irrigation improve, and the opposition to transfers developed in the decade 1965-1975 becomes more moderate and willing to compromise, we should see interbasin transfer treated as one of a number of viable options in irrigation water supply development.

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ABSTRACT

Industrial and social objectives of the 1950 Kemano Project were fulfilled by building an ambitious engineering undertaking which increased Canadian hydroelectricity generation, aluminum smelting capacity, and created new centers of population in a remote region of British Columbia. However, significant biophysical and social impacts were induced such as the loss of fish habitat, drowned forests, and the forced relocation of local Indian bands. A cost-benefit analysis reveals that overbuilding and declining aluminum prices made the project uneconomic from a social perspective.

A tripartite Nechako River Flow Agreement was finalized on 1 January 1988 by Alcan, the Federal Department of Fisheries and Oceans, and the British columbia Ministry of energy, Mines and Petroleum Resources. It permitted Alcan to increase its diversion of the Nechako while protecting downstream Chinook salmon. In return, Alcan gave up its right to direct the Nanika River into the Nechako. All public interest groups were excluded from those negotiations. There was no effort made to redress losses experienced by the Cheslatta Band 35 years earlier.

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INTRODUCTION

The provincial government entered into an agreement with the Aluminum Company of Canada (Alcan) in 1950 to develop hydroelectricity and to establish an aluminum industry in midwestern British Columbia. The Kemano project, as it became known, was considered an engineering wonder at the time and one of the most stable industrial developments ever undertaken in the province. However, it also induced some negative impacts such as reduction of chinook salmon stocks, and flooding of Indian reserves forcing all affected bands to relocate.

In 1978 the Aluminum Company of Canada began to consider the Kemano Completion Project to expand the existing smelting and power capacity. Although the company devoted considerable effort to developing a socially desirable expansion, this new undertaking did not include a formal hindsight assessment of the existing project. Such an evaluation would attempt to determine project characteristics that should be retained and enhanced, and those which should be corrected in order to balance economic efficiency and equity with social and ecological stability. That is the aim of the present study.

A simplified version of the method developed by Day et al. (1977) for hindsight project evaluations is used in this study. An extensive literature review was conducted to obtain relevant data. Additional information was obtained in a visit to the smelter site during the summer of 1985, and from key interviews conducted with project participants during 1986.

PROJECT DESCRIPTION

Interest in the Kemano can be traced back to the 1920s, when the idea to redirect waters of rivers and lakes of central western British Columbia from east to west was first conceived. Government surveys confirmed the hydroelectric potential. But the enormous distance from load centers, and the large size of power increments, suggested that only an energy-intensive industry such as aluminum smelting located at the source would make such a project feasible. Alcan was invited in 1941 to develop the power potential and establish an aluminum smelter. The rising commercial, industrial, and military demand for aluminum along with generous government assistance such as relaxed taxation and low resource royalties made the project attractive. However, the studies and negotiations were postponed as a result of World War II. Then in the late 1940s provincial legislation was passed and an agreement signed with Alcan to make the project possible. From the provincial perspective this undertaking allowed the development of power, the establishment of a permanent industry, and the beginning of a new center of population (British Columbia and Aluminum Company of Canada,1950, 2-3).

The Province of British Columbia granted a water licence and a permit to occupy crown land as part of the agreement. The licence allows Alcan to store a maximum of 43.2 km^3, and divert up to 269 m^3/s from the Nechako River at the Kenny Dam, Skins Lake, and the Nanika River from 3.2-km below Kidprice Lake (fig. 1) (British Columbia, Department of Lands and Forests, 1950a). Annual water rentals are based on horsepower-year units at 1.67 times the average price of aluminum at Kitimat for power used in aluminum smelting. The permit allowed the corporation to flood all land below elevations 859.5 m in the Nechako and Skins Lake basins and 950.9 m on the Nanika basin, and granted other land needed for construction and operation of the works. The total area of occupation was estimated at 777 km^2 (British Columbia, Department of Lands and Forests, 1950b). Annual crown land rentals were set at 0.33 times the price of aluminum times the flooded area. Timber on occupied lands could be destroyed, damaged, drowned, or removed without stumpage or royalty fees, and protection against staking for minerals, petroleum, and gas was also granted. It was also agreed that the company could sell electric power but could not be compelled to do so. Water rights were guaranteed in perpetunity if Alcan developed hydroelectric capacity equivalent to 298 MW by 1963, and at least 560 MW by 1983. A final water licence will be granted on 31 December 1999 based on the total installed generating capacity (British Columbia and Aluminum Company of Canada, 1950, 4, 6, 9-10).

Today, the Kemano I project has the following components (fig. 1):

1) Hydraulic structures which include: a) the 100-m high, rock-filled, clay-core Kenney Dam at the entrance to the Grand Canyon to store the flow from 14,115 km^2 of the upper Nechako River watershed, a tributary of the Fraser River system, and create the 906-km^2 Nechako Reservoir with 4.95-billion m^3 of live storage (Jomini, 1954, 6; Wolcott, 1954, 3-4); b) a 16-km tunnel to transport the water flow through Mount Dubose providing a 792-m drop to the powerhouse; and c) a spillway at Skins Lake to regulate water levels by releasing water through the Cheslatta River-Cheslatta Lake-Murray Lake system before entering the Nechako River at Cheslatta Falls.

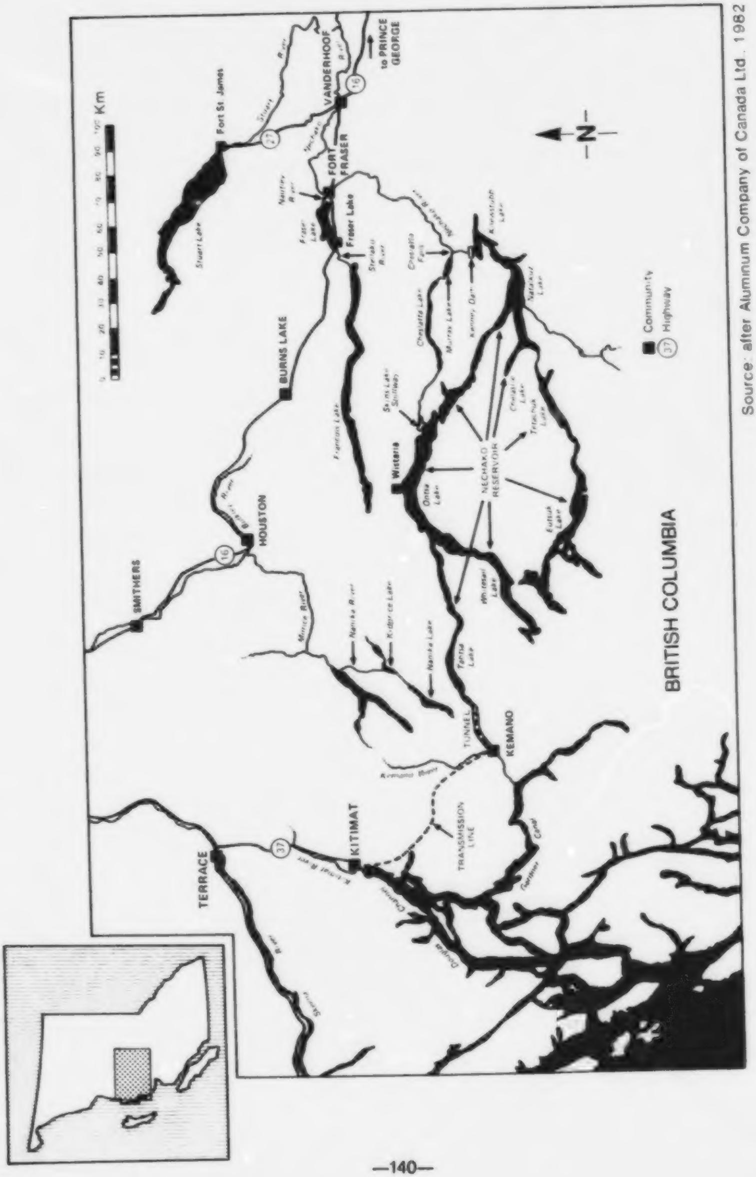
2) The Village of Kemano and the 896-MW powerhouse built inside the base of Mt. Dubose. Water from the power plant is discharged into the Kemano River and ultimately into the Pacific Ocean through the Gardner Channel.

3) The 82-km double transmission line to transport Kemano energy to the smelter site.

4) The Town of Kitimat, a deep sea port, and the aluminum smelter which are located in a sheltered valley at the head of the Douglas Channel. Kitimat has year-round connection by water to the Pacific Ocean, 120-km to the west. The current smelter capacity is 268,000-tonne per year. The Kitimat plant is the second largest aluminum smelter in the free world (Alcan Smelters and Chemicals, n.d.a, 7, 11).

Figure 1

The Kemano Diversion


Km
0 10 20 30 40 50 60 70 80 90 100
Stuart Lake
Fort St James
Stuart River
27
VANDERHOOF
Nechako River
16
to PRINCE GEORGE
FORT FRASER
Nautley River
Fraser Lake
Fraser Lake
Stellako River
BURNS LAKE
Francois Lake
Cheslatta Falls
Cheslatta Lake
Murray Lake
Kenney Dam
Knewstubb Lake
Natalkuz Lake
Skins Lake Spillway
Wistaria
Ootsa Lake
NECHAKO RESERVOIR
Chelaslie Lake
Tetachuk Lake
Eutsuk Lake
Whitesail Lake
Tahtsa Lake
HOUSTON
Bulkley River
16
SMITHERS
Morice River
Nanika River
Kidprice Lake
Nanika Lake
TUNNEL
KEMANO
Kemano River
TRANSMISSION LINE
KITIMAT
37
Kitimat River
TERRACE
Skeena River
Douglas Channel
Gardner Canal
N
Community
37 Highway
BRITISH COLUMBIA

Source: after Aluminum Company of Canada Ltd. 1982

BIOPHYSICAL IMPACTS

Streamflow and River Morphology. Several rivers were modified as a result of the Kemano Project. Among them, the upper Nechako River suffered the greatest disruption. The average 205 m^3/sec flow was completely stopped during reservoir filling from October 1952 to December 1956, and flow downstream of the Kenney Dam to the Nautley River reach was restricted to the small Cheslatta River drainage (Canada, Department of Fisheries and Oceans, 1984, 30-1). Once the reservoir was full, the flow was partially restored with releases through the Skins Lake spillway which averaged 60% of the prediversion levels at Cheslatta Falls. However, this reduction was not evenly maintained; relatively large flows prevailed during the first 10 years, but gradually decreased and reached record low levels during the late 1970s as more water was diverted to the Kemano powerhouse (Canada, Department of Fisheries and Oceans, 1984, 31). The trend continued until 1980 when legal action was taken by the federal Department of Fisheries and Oceans (DFO) forcing Alcan to release water according to a predetermined schedule. Since then, the Nechako flow below Cheslatta Falls has averaged 61 m^3/sec (Canada, Water Survey of Canada, 1985, 603), or 30% of average prediversion conditions. The flow reduction and diversion had two negative effects: 1) the 7.5-km reach between the Kenney Dam and Cheslatta Falls was dried up, and 2) the lower Nechako flow caused erosion at the mouth of the Nautley River which had deepened 1.8 m by 1953 (Kraft, 1954, 69). On the other hand, the elimination of potentially harmful high flows helped to reduce flood risk throughout the Fraser River (Canada, Fisheries and Marine Service and International Pacific Salmon Fisheries Commission, 1979, 4).

Major changes occurred in the Kemano River as well. To its 43 m^3/sec natural flow at the point of confluence with the diversion inflow from the Nechako Reservoir (Canada, Water Survey of Canada, 1985, 432), Alcan's powerhouse added volumes ranging from 25 m^3/sec in 1955 to 124 m^3/sec in 1979. Downstream morphological effects associated with greater mean flows on the Kemano River include straightening and widening of the channel zone, and channel length shortening (Kellerhals et al., 1979, 19; Canada, DFO, 1984, 41).

The Cheslatta River, a small Nechako River tributary, was used as the spillway for releases from the Nechako Reservoir to regulate water levels. This stream had an average flow of 5-m^3/sec traversing about 70 km through Skins, Cheslatta, and Murray lakes (Canada, DFO, 1984, 30), before joining the Nechako River at Cheslatta Falls, about 7.5-km downstream from the Kenney Dam (fig. 1). After reservoir releases started in 1957, spillway flows averaged 138-m^3/sec, and a maximum flow of 507-m^3/sec was registered. These much higher flows caused several river changes, including: a) extensive erosion in the spillway, b) increased channel width from 5 m to 75-150 m, c) channel entrenchment by 5-10 m below the former flood plain, d) fan dissection of tributaries, e) drainage of the three small lakes, f) silt deposition and subsequent loss of depth in Cheslatta Lake, and g) extensive and progressive erosion of bedrock in the vicinity of Cheslatta Falls (Kellerhals et al. 1979, 20-21).

Salmon. Impacts on salmon have been the subject of major project criticisms. Initially, the International Pacific Salmon Commission (IPSFC) feared that lower river flows could increase water temperatures which had exceeded critical levels in the past (Canada, Department of Fisheries and IPSFC, 1952, 39). After reviewing all available evidence, the salmon commission recently reported that fortuitous timing had prevented potential major sockeye mortality attributable to warmer temperatures observed over the years following project completion (IPSFC, 1979, 29).

Impacts on upper Nechako River chinook salmon, also called "spring," were more severe. Stream bed dewatering during reservoir filling and heavy siltation from the Cheslatta system caused drastic declines in the number of spawning chinook. They declined to about 100 from historical levels of about 2500 (Canada, Fisheries and Marine Service and IPSFC, 1979, 11, 17).

Federal fisheries failed to adequately protect the Nechako River salmon when the project was built. Unfortunately it did not insist on protective measures to mitigate the potentially harmful effects of higher water temperatures, and assure minimum flows which are critical to protect chinook stocks downstream of the Kenney Dam.

The average flow to the Kemano powerhouse reached a record 124-m^3/sec in 1979, and releases through the Cheslatta system diminished significantly after Alcan signed a special contract to supply power to the British Columbia Hydro grid in November 1978. In response, DFO went to the courts and obtained an injunction in August 1980 ordering the company to release water according to a predetermined schedule. During the trial the company argued that section 20 of the Fisheries Act, under which the action was launched, was unconstitutional as it encroached on provincial jurisdiction to manage inland waters. Moreover, it asserted that the required schedule of flows was arbitrary, unsupported by evidence. Justice Berger decided the constitutional question in favor of the minister, and ruled out Alcan's evidence on required flows (British Columbia, Supreme Court, 1980). Alcan complied with the court order at once, and undertook further studies which contradicted the minister's opinion concerning a suitable flow schedule.

Pollution. Smelter flouride emissions were a major irritant. The amount of flouride released from the Kitimat smelter was directly related to the smelter expansion program and operating conditions. Emission levels were high during the first 15 years of operations but decreased when improved pollution abatement technology was installed during the 1970s. The consequences of high flouride exposure on Kitimat Valley vegetation were twofold: 1) there was an unexplained relationship related to a decimation of trees impinged by saddleback looper, spruce budworm, and bark beetle from 1960 to 1969 (Alcan Surveillance Committee, 1979, 102), and 2) there was a growth loss of between 19% and 28% on 7042 ha of forest land, and the total destruction of trees over 32 ha immediately north of the smelter (Reid and Collins, 1976 cited in Alcan Surveillance Committee, 1979, 71, 74). It is likely that future forest losses will not be as severe. Recent smelter improvements lowered flouride levels in vegetation by as much as 60% between 1976 and 1983 (Rice, 1984 cit. in Canadian Association of Smelter and Allied Workers, 1986, 114).

The effect of smelter effluents on the aquatic environment was largely unexplored until recently. A comprehensive literature review concerning the Kitimat estuary concluded that smelter effluent discharges had 3 effects: 1) deposition of inert carbon particulates on the western Kitimat River delta, 2) elevated fluoride concentrations in contiguous waters, and 3) habitat degradation in the immediate vicinity of Alcan's main discharge point (Bell and Kallman, 1976, 144, 166).

Smelter workers may have been detrimentally affected by flouride emissions too. Indeed, from the union perspective, "no single issue has dominated labor relations as much as this concern" (Canadian Association of Smelter and Allied Workers, 1986, 109). A union-commissioned study reported significant relationships between increased exposure levels to flourides and obstructive pulmonary changes as well as bone abnormalities (Canadian Association of Smelter and Allied Workers, 1977). Further studies involving the provincial Workers Compensation Board, Alcan, and the union confirmed the lung problems. Several cancer cases were also detected, which are potentially related to working conditions. This question is currently under study (Papenbrock, 1986).

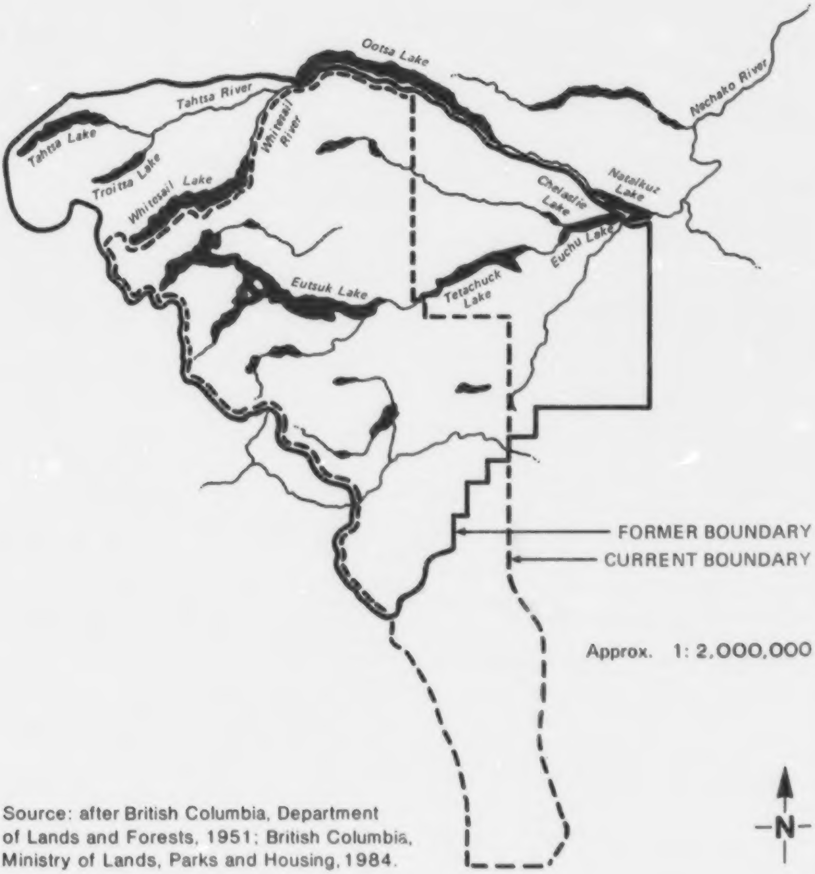
Parks. A significant impact caused by the Kemano Project was the modification of the Tweedsmuir Park boundary. This vast, primitive area had a 400-km circle of large-to-small lakes connected by short-to-medium portages which was lost when the original park area of 1.4-million ha was reduced to 1.0-million ha. The boundary was modified to exclude eastern and western lakes and rivers from the jurisdiction of the park to create the large Nechako Reservoir (Velay, 1985) (fig. 2).

SOCIOECONOMIC IMPACTS

New Communities. The Kemano project created two new communities in British Columbia. Kitimat, the smelter and port town, is recognized as the first planned, single-industry town in Canada. Its public services and facilities, which include recreation complexes, a library, museum, and a golf course, are the envy of similar remote communities. Its population was formed by new immigrants, usually poor, unskilled workers who came from European countries to take advantage of Alcan's steady work and subsidized public services and housing (Kendrick, 1985). Over the years, Alcan's stable operations made Kitimat a properous community, with relatively few work interruptions. The original smelter work force of about 2200 has practically remained constant since the first aluminum ingot was poured in 1954. Today, a forest products firm and a methanol plant also have operations in Kitimat, contributing to its economic diversification and the maintenance of a permanent population of 12,000.

The scenic town site of Kemano, population 250, also has good facilities. It is located in a small valley surrounded by steep mountains where hunting and fishing opportunities abound. There is little literature about socioeconomic conditions prevailing at Kemano but one report indicates that Kemano residents are generally favorable toward their community, and very satisfied with the quality of their lives (Alcan Smelters and Chemicals, 1982). However, there is persistent dissatisfaction with the perceived heavy involvement of Alcan in community affairs, and with limited transportation to other sites which is restricted to a twice-a-week, company-owned ferry to Kitimat.

Figure 2. Tweedsmuir Park boundary changes resulting from the Kemano Diversion.


Ootsa Lake
Tahtsa River
Tahtsa Lake
Troitsa Lake
Whitesail Lake
Whitesail River
Nechako River
Chelaslie Lake
Natalkuz Lake
Euchu Lake
Tetachuck Lake
Eutsuk Lake
FORMER BOUNDARY
CURRENT BOUNDARY
Approx. 1: 2,000,000
N

Source: after British Columbia, Department of Lands and Forests, 1951; British Columbia, Ministry of Lands, Parks and Housing, 1984.

Impacts on Indians. The Cheslatta Band was significantly affected by the Kemano I project. Their livelihood was based on hunting, fishing, and trapping until their lives were changed by the project. Some of their reserves were flooded by the Nechako Reservoir, by spillway releases on Cheslatta Lake, and the construction of a temporary dam for fisheries protection on the Cheslatta River. Available literature suggests that government officials failed to adequately protect the band's interests. A hasty deal was reached only a few days before the water started to rise, forcing band members to evacuate their properties immediately. In comparison to white settlers living at Ootsa Lake, the Cheslatta were not compensated for trapline losses and were paid marginal prices for their land (Beck, 1983, 46; Boyer, 1956, 398; Lush, 1985). Indeed, evidence indicates that white settlers who understood English and knew how the provincial institutions operated, received much higher compensation for their flooded properties than their Indian neighbors. In an attempt to regain some of their losses, the band filed a claim with the federal Department of Indian and Northern Affairs (DINA) in April 1984 (Lush, 1985). In response, the federal Department of Justice recommended that DINA should accept the claim since the band had received only partial compensation for the losses it experienced. If the recommendation is accepted by the band and the minister, negotiations for a suitable compensation package will be undertaken (Vranjkovic, 1986).

Economic Impacts. No comprehensive evaluation of macroeconomic impacts created by the original Kemano project has been prepared to date. A partial evaluation was prepared for Alcan to assess the impacts created during selected years of capital expenditures and operations. The study estimated significant contributions to the Canadian economy by virtue of the project's contribution to employment and the gross national product. It showed that Ontario benefited more than British Columbia as a result of Kemano I due to its disproportionately high share of Canadian manufacturing (Alcan Smelters and Chemicals Limited, n.d.b. ii, 46). However, these findings should be used with caution since the econometric model used in the study was unable to simulate the Canadian economy during the 1950s, and because the provincial allocation of impacts was based on an estimate during a hypothetical time period.

An alternative evaluative technique, cost-benefit analysis (CBA), was used to estimate the economic value of the project. CBA differs from macroeconomic analysis in several ways. It measures project efficiency by comparing the social value of all costs, the resources utilized such as labor, capital, and hydroelectricity, with the social value of all the positive impacts or benefits created. An extensive literature search was conducted to obtain relevant data. The reader is advised to consult Gomez-Amaral (1987) for a detailed review of assumptions and sources. The gross national expenditure (GNE) price index of Statistics Canada (catalogue 13-201) was used to convert all data to 1985 dollars, and Canadian dollars equivalents were estimated using catalogue 67-201 when the data were in foreign funds.

Annual revenues from aluminum sales, averaging $ 426 million ($1985) per year over 1955 to 1985, were estimated from the international aluminum ingot prices, and the smelter output. These data were corrected to estimate the foreign exchange benefit since most of the Kitimat output is exported. The other major project benefit was derived from power sold to third parties. The company supplied about 550 GWh annually to Kitimat, Terrace, and Prince Rupert. After those communities were connected to the provincial grid in 1978, Alcan arranged a 5-year contract to supply BC Hydro with a minimum of 1200 GWh of energy annually for the export market. The value of these sales was estimated at $4 million ($1985) per year over 1955 to 1975, and at about $50 million ($1985) over subsequent years, as a result of greater power sales and higher energy prices. A premium for energy saving benefits was added to these estimates since, in the absence of Kemano power, the communities would have satisfied their power needs with alternative, more expensive sources such as coal or diesel fuel. Flood control on the lower Fraser River and fisheries on the Nechako Reservoir are unquantified benefits whose value should also be included when data become available.

The number of project costs was larger and their estimation more difficult given the confidential nature of many company data. Capital costs, originally estimated at $500 million, were calculated at about $ 3.2 billion ($1985), including the cost of expanded power facilities in the 1960s, highway and railroad construction, and a recent modernization program to improve smelter efficiency and to satisfy pollution controls. Operating and maintenance costs were divided into labor, power, alumina, and other costs and conservatively estimated from publicly available sources at about $1250 per tonne of aluminum ($1985). Considering the increasing annual production levels, this cost has ranged from about $174 million ($1985) per year in the first years of operations to more than $300 million ($1985) per year over the last decade. No consistent data were found to estimate several external costs such as the loss of recreational opportunities and wildlife habitat in Tweedsmuir Park, and the reduction of Nechako River salmon populations. The value of these items should also be included in the analysis when information is available.

An estimate of the net economic benefits attributable to Kemano I was made based on the "forward value" (FV) in 1985 of the stream of benefits and costs since the project began. This approach is analogous to the normalization procedure performed for ranking projects through the compound interest formula cited in British Columbia, Environment and Land Use Committee Secretariat (1977, 79-84). An 8% social discount rate was chosen as a base case, and rates of 10% and 6% were used for sensitivity purposes. The results of the exercise are presented in table 1. Benefits not adjusted for date of occurrence exceed total costs by over $2.4 billion. However, the FV of net benefits at a 8% social discount rate is $-11.3 billion. Similarly, FV estimates at 10% and 6% discount rates are $-26.2 billion and $-3.5 billion, respectively. Two factors should be noted in understanding the difference between unadjusted and adjusted net benefits: 1) most project capital costs occurred at the beginning of the project and compounding significantly augments their weight, and 2) compounding augments the effect of low real aluminum prices from the late 1950s to 1972.

The net present value (NPV) of future net benefits to be created from investments already made should also be added to arrive at an overall project efficiency estimate. Assuming a 20-year economic life of existing facilities, completion of the current modernization program, and average net benefits similar to those observed over 1976 to 1985, the NPV of future net benefits were estimated at $3.0, $2.6 and $2.2 billion at 6%, 8% and 10% social discount rates, respectively. In effect, the NPV of net benefits beyond 1985 are less than the FV estimates, and therefore insufficient to turn positive the project's overall present value, even at a low 6% social discount rate. Therefore, results suggest the original Kemano Project has not been justified from a social cost-benefit perspective.

Table 1

SOCIAL COSTS AND BENEFITS CREATED BY THE KEMANO I PROJECT: 1951-85

(millions of $1985)

	---- Benefits	----		--- Costs	---					
Year	Aluminum	Power	Total	Capital	O&M	Total	Net Benefits	FV r= 10%	FV 8%	FV 6%
1985	381	44	425	30	330	360	65	65	65	65
1984	480	44	524	30	313	343	181	199	195	192
1983	490	44	534	95	300	395	139	168	163	156
1982	379	44	423	30	325	355	68	90	86	81
1981	586	44	630	30	328	358	272	397	370	343
1980	742	44	786	30	319	349	437	704	642	586
1979	692	44	736	-	319	319	417	738	663	592
1978	564	44	608	-	319	319	289	564	494	434
1977	572	66	638	-	319	319	319	683	590	507
1976	504	66	570	14	319	333	237	559	474	401
1975	371	6	377	-	263	263	114	295	246	204
1974	615	6	621	-	327	327	294	838	685	559
1973	466	6	472	-	327	327	145	455	365	291
1972	346	4	350	-	316	316	34	117	92	72
1971	371	4	375	-	303	303	72	274	212	163
1970	313	4	318	-	211	211	107	447	339	257
1969	510	4	515	-	329	329	186	854	638	472
1968	446	4	451	-	299	299	152	768	562	409
1967	467	4	472	-	290	290	182	1012	728	519
1966	412	4	416	348	263	611	-195	-1193	-842	-591
1965	281	2	283	-	174	174	109	734	508	350
1964	263	2	265	-	174	174	91	673	458	309
1963	264	2	266	-	174	174	92	749	500	331
1962	285	2	287	-	174	174	113	1011	663	432
1961	303	2	305	-	174	174	131	1290	831	531
1960	300	2	302	-	174	174	128	1386	877	582
1959	333	2	335	-	174	174	161	1919	1191	776
1958	348	2	350	-	174	174	176	2307	1406	848
1957	377	2	379	284	174	458	-79	-1139	-682	-404
1956	373	2	375	290	174	464	-89	-1412	-829	-482
1955	363	2	366	238	174	412	-46	-803	-463	-264
1954	-	-	-	444	-	444	-444	-8520	-4826	-2704
1953	-	-	-	441	-	441	-441	-9310	-5177	-2844
1952	-	-	-	458	-	458	-458	-10639	-5807	-3133
1951	-	-	-	489	-	489	-489	-12494	-6694	-3545
Totals	13195	557	13752	3251	8034	11285	2467	-26214	-11277	-3505

Notes: O & M = Operation and Maintenance; F V = Forward Value; r= Discount Rate. Power benefits include sales revenue and avoided energy costs. Aluminum benefits include foreign exchange benefits. Totals may not add due to rounding. See text for details.

An examination of water rentals paid for power generation under the original 1950 agreement was also conducted. The analysis showed that the rate has been inconsistent with the value of power for aluminum smelting purposes. Over the last decade, when energy prices increased significatively, the province collected about $ 0.2 per MWh ($1985) in power rentals, instead of $19.4 per MWh according to opportunity cost principles. No evidence was found to suggest that water rentals were collected through alternative means such as taxation by either level of government. In effect, the province received a significantly lower value for water used for hydroelectricity generation than was paid by B.C. Hydro.

The Nechako River Flow Agreement. In 1978 Alcan proposed the completion of its hydroelectric development to increase aluminum smelting capacity in north-central British Columbia. The development would cost over $2.2 billion. It would divert 80% of the natural mean annual discharge of the Nechako River, and 62% of the mean annual discharge of the Nanika River in the Skeena catchment (fig. 1), to the Kemano River. Another powerhouse would be built at Kemano which would permit an increase in aluminum production from 240,000 to 582,000 tonnes annually. The project would generate 1500 permanent jobs and several thousand man-years of temporary construction (Canada 1984:iv)

There has been continuing disagreement over water allocation in the region. Alcan was ordered by the Supreme Court of British Columbia to increase flows in the Nechako in 1980 in support of an appeal by the federal Department of Fisheries and Oceans (DFO). Alcan challenged DFO's right to control the Nechako River flow in 1985 and reached an out-of-court agreement with the province and federal fisheries officials on 14 September 1987 for a drastically revised flow regimen and project proposal. Under it, Alcan surrendered all water rights to Nanika River flow. Alcan will build a cold-water release facility ($25 million) around Kenney Dam to control downstream water temperature and protect spawning chinook salmon as well as sockeye which migrate through the Nechako River to spawn in other streams. However the Province of British Columbia assumed the financial responsibility to mitigate any negative impacts on resident trout and char populations in the Nechako which may be detrimentally affected by the agreement (Strachan 1987). Under the agreement, Alcan is permitted to reduce Nechako River flow by 42% below the average flows of the 1980's, or to less than 20% of the prediversion flows (Alcan et al. 14 Sept. 1987:schedule D). This will permit an increase in generating capacity of 300 MW at Kemano for a total installed capacity of 1080 MW.

This agreement creates several major changes from the circumstances under which the Kemano Diversion operated for over 30 years. The incremental diversion water made available is not tied directly to creating new smelter capacity or new permanent jobs. Indeed, the agreement does not require Alcan to create new smelter capacity or new permanent jobs. It appears that eventually new energy produced could be exported if the free trade agreement between Canada and the United States is ratified (Canada 1987:30). There were no provisions to enable the province to obtain higher water rental payments on any energy produced from the new diversion which is sold for use in British Columbia or the United States.

The 1987 tripartite agreement was negotiated in complete secrecy. While many have an interest in the river, only ALCAN, DFO, and the provincial Ministry of Energy, Mines and Petroleum Resources were represented in the negotiations. The federal government could have used Federal Environmental Assessment and Review Process, or the province could have used its Energy Review Process, to appraise the agreement in public. As a result, the fishermen's union and the Rivers Defence Coalition denounced the agreement and have called for a more open decision making process to decide the uses and allocation of waters in all provincial rivers (Siddon's ... 1987:4). They may also challenge the legality of the agreement in the courts.

CONCLUSIONS AND RECOMMENDATIONS

The study reveals that the industrial and population objectives of the provincial and federal governments associated with the Kemano project were largely fulfilled. New communities were created, a major hydroelectric plant was built, and a new, permanent industry was established. On the other hand, there are some features of the 1950 agreement, such as the fixed water rental rates, its tenure in perpetuity, and the protection against future agreement amendments, which should be considered unacceptable today. Therefore, it is recommended that the province should avoid making long-term commitments in future with private project developers where flexibility in terms and conditions is lacking.

An unfortunate episode of the Kemano development relates to the treatment of the Cheslatta Band who lived in areas affected by flooding and reservoir releases. As opposed to white settlers in adjacent Ootsa Lake, band members were forced to evacuate their homes on short notice and were belatedly paid marginal compensation. It is recommended that the Department of Indian and Northern Affairs should ensure a rapid and fair settlement of the Cheslatta Band claim for losses experienced during construction of the Nechako Reservoir more than 35 years ago.

A social cost benefit analysis reveals that project costs exceeded project benefits even considering future net benefits accruing from existing investments using a low 6% social discount rate. Large initial capital expenditures are the dominant factor to explain the poor economic performance of the project.

* Project impacts were not managed adequately by today's standards. The disruption of chinook salmon habitat and the increased risk of sockeye losses on the Nechako River are among the potential biophysical effects. To avoid such impacts which disadvantage specific social groups, it would have been useful to create a multilateral Nechako River management committee composed of local politicians, Alcan representatives, natives, fishermen, recreationists, and appropriate provincial and federal agencies. Now that the agreement has been finalized, the opportunity has been lost to forge an agreement which would have better served multiple purposes in the basin.

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RIVER DIVERSIONS IN NORTHERN QUEBEC:

LEARNING FROM THE LA GRANDE COMPLEX.

ALAN F. PENN[1]

ABSTRACT

The La Grande hydro-electric complex in Northwestern Québec accounts for ca. 40% of inter-basin transfers in Canada; planned development of rivers North and South of the La Grande may increase transfers in this region by 50% in the next 20-30 years. Little government or university-based research has been directed at the impacts of these diversions, but insights derived from monitoring by La Société d'Energie de la Baie James now permit re-evaluation of initial environmental issues, and suggest directions for future research and monitoring.

Construction of this project will span 30 years (1971-ca.2000). Public debate in the early 1970's about the 'James Bay project' (including hearings for an injunction) preceded definition of the eventual diversion routes. Major design changes followed in 1978, 1979 and 1986, of which the ecologically most significant may be the adoption of a 60% load factor (rather than 80%). Four more power plants will be built in the next 12 years. Both the time-scale and the evolving design challenge our ideas about the scope and objectives of impact assessment and ecological monitoring as applied to inter-basin transfers.

Environmental concerns have also evolved with time. Flow reduction at the Eastmain and Caniapiscau estuaries, and the magnitude of flooding, drew attention at the outset. The focus now is on the transport of mercury and its uptake by fish, and the effects of flow augmentation in winter. An extra 30 km^3 of freshwater under shelf ice may affect eel-grass ecosystems used by migratory waterfowl; and changed flow conditions may radically affect anadromous stocks of whitefish and trout. The banks of the lower La Grande River are also attracing attention; high winter flows and daily water level changes are exposing marine sediments and triggering widespread instability.

Les détournements faisant partie du Complexe La Grande dans le nord-ouest québécois représentent environ 40% des transferts inter-bassin au Canada. D'ailleurs, l'aménagement projeté d'autre rivières vers le nord et le sud pourraient augmenter ce chiffre de 50% au cours des prochaines 20-30 années. Peu de recherche gouvernementale ou universitaire nous renseigne sur les conséquences écologiques de ces détournements. Cependant, le suivi effectué par la Société d'Energie de la Baie James nous permet de réévaluer les impacts environnementaux tel qu'initialement prévus, et d'identifier des priorités pour ce qui est de la recherche et du suivi dans l'avenir.

La réalisation du Complexe La Grande s'échelonnera sur une période d'environ 30 ans (1971 - ca. 2000). La publicité qui entoura "le développement de la Baie James" (y compris la requête en injonction), précéda la définition du schéma des détournements de rivières qui fut retenu eventuellement. D'autres modifications d'envergure furent apportées au projet en 1978, 1979 ainsi qu'en 1986 (dont l'adoption d'un facteur d'utilisation de 60% pour l'ensemble du Complexe fut probablement la plus importante sur le plan écologique). La construction de quatres autres centrales se déroulera probablement au cours des douze prochaines années. Ce genre d'échéancier, ainsi que l'évolution de la conception même du projet nous obligent à repenser plusieurs de nos principes d'évaluation environnementale et de suivi écologique s'appliquant aux détournements de rivières.

Les préoccupations d'ordre environnemental ne sont pas immuables non plus. D'abord, ce fut l'inondation des terres et les effets de la coupure des débits aux estuaires des rivières Eastmain et Caniapiscau qui ont surtout retenu l'attention. A l'heure actuelle, on se préoccupe davantage du transport du mercure et de son assimilation par le poisson, ainsi que des effets d'augmentation des débits en hiver. Les 30 km3 supplémentaires d'eau douce sous la banquise de la Baie James pourraient entraîner des répercussions importantes sur les herbiers de zostère exploités par la sauvagine, tandis que les modifications hydrauliques en aval des aménagement pourraient compromettre la survie des populations anadromes de corégones et de truites. On accorde également beaucoup d'attention aux berges de la La Grande rivière; les débits d'hiver, associés aux fluctuations des niveaux d'eau, provoquent l'érosion des sédiments marins ainsi que le déclenchement de glissements de terrain.

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INTRODUCTION

This paper, like those by Roy and Messier in the same volume, is about the impacts of inter-basin transfers of water associated with the La Grande hydro-electric project in Northern Québec. It draws upon, but generally seeks to avoid repeating, the material contained in their papers. Unfortunately, Roy and Messier were unable to deliver their papers in person at the Saskatoon symposium on inter-basin transfers; the oral presentation on which this text is based was therefore aimed at a reasonably self-contained evaluation of the impacts of the La Grande development. I have tried to maintain that balance in the text that follows.

I want to focus, however, not so much on a description or inventory of ecological impacts that have been observed as on the larger issues of identifying what it is that we should consider 'significant', and how the experience acquired, mainly during the last ten years, should influence decisions about additional information that we need about the La Grande development as well as our approach to the planning and impact assessment of inter-basin diversions likely to be built in the future. What features of diversions in the Canadian North should be used in developing criteria for assessing future transfers, or indeed in deciding whether they should take place? Under what conditions should they be built? What is the scope for remedial measures? These are not academic questions, at least not in northern Québec. Present equipment programmes of Hydro-Québec indicate that the development involving the diversion of the Little Whale and Boutin rivers into the Great Whale River, and the routing of all three into Manitounuk Sound, will be built during the 1990's. Furthermore, construction of the much discussed and technically difficult Nottaway-Broadback-Rupert Complex (NBR - the original 'James Bay project'), involving the rivers of the southern James Bay territory, may begin before the turn of the century.

Some words may help to clarify the perspective from which this text was written. The author acts as an advisor to the regional native organization (the Cree Regional Authority) which offers technical support to the Cree communities of the James Bay region. These services include advice related to impact assessment, monitoring and the planning of remedial measures. Of course, collaboration with the James Bay Energy Corporation and Hydro-Québec are essential ingredients in this function. Nevertheless, this also means that the native communities - and the Cree Regional Authority - are largely dependent on information collected by these Crown corporations and their consultants. Indeed, this paper is largely based on material collected and supplied by them; and their support in this respect is gratefully acknowledged.

We should keep in mind, though, that there has been almost no government sponsored research in the region related to the ecological assessment of inter-basin diversions, either Federal or Provincial. Given the scale of the diversions (discussed in more detail below), this itself is an interesting commentary on the extent to which such transfers have, in fact, attracted the attention of government decision-makers. It is also relevant to remember that the La Grande development was not authorized on the basis of impact assessment; and that key decisions about both the Great Whale and NBR developments have also already been taken without the benefit of formal assessment of ecological impacts (see, for examples, 8.1.2 and 8.1.3 of the James Bay and Northern Québec Agreement: JBNQA, 1976).

THE LA GRANDE HYDRO-ELECTRIC COMPLEX

If we are to appreciate the ecological ramifications of the La Grande development, we must know something about the way the project was designed and built. The scheme that we know today has evolved considerably since the project was announced in the spring of 1971, and major changes have been made while construction was in progress. By the mid-1980's, we had a pretty good idea what the final product would look like, but construction will probably come to an end at the turn of the century. We are dealing, therefore, with a project whose construction spans roughly thirty years, of which the design evolved over a period of at least fifteen years. These simple facts are rarely commented upon, and often overlooked. The implications for environmental impact assessment are far-reaching; but formal assessment procedures for such developments apparently do not reflect the way such projects are, in reality, planned and executed. It is worth taking a few minutes to see what happend in the case of the La Grande.

The La Grande development is on a large scale. Research for the Inquiry on Federal Water policy (Pearse _et al_. 1985) helps to place this diversion scheme in a Canadian perspective (Day, 1985; see also Rosenberg and co-workers in Healy and Wallace, 1987). Canadian society has invested heavily in interbasin transfers, mainly for hydro-electric development. This has been greatly facilitated by the centripetal drainage of the Canadian Shield, low divides between catchments, and low population density along northern rivers. Thus Quinn (1981) was able to observe that Canada's interbasin transfers exceed the combined totals for the Soviet Union and the U.S.A. Within Canada, the La Grande scheme accounts for about 36% of all interbasin transfers (mean annual flow of 1600 m^3/sec of a total of 4400 m^3/sec). The completion of the Great Whale and Nottaway-Broadback-Rupert (NBR) Complexes will eventually raise northern Québec's contribution to this total by a further 50%. No discussion of interbasin transfer policy in Canada which overlooks northern Québec could reasonably be considered complete. Yet the State of the Environment Report for Canada (Environment Canada, 1986), in a chapter on restructured aquatic ecosystems, is silent on the La Grande development.

The interbasin transfers of the La Grande Complex described by Messier and by Roy in their papers is the product of investigations of alternative diversions carried out between 1971 and 1974 (Société d'énergie de la Baie James, 1987, ch.3). Diversion and development of the Nottaway, Broadback, Rupert, Eastmain, La Grande and Great Whale rivers were all examined. In 1972, it was decided - mainly for engineering reasons - to focus first on the development of the La Grande river and later on the southern rivers (Nottaway, Broadback and Rupert). A number of different variants were then considered. Eventually, in early 1974, the Energy Corporation decided to divert most of the Opinaca and Eastmain drainage north to the La Grande, and leave the Great Whale River for separate development along with the Little Whale and Boutin rivers. It was also decided, at this stage, to divert about 40% of the Caniapiscau catchment towards the La Grande. It is well known, I think, that the Cree and Inuit sought an injunction against this development in 1972 and negotiated an agreement-in-principle for settlement of aboriginal claims in the territory in 1974; it is less widely known or appreciated that, at the time of the protracted hearings in Québec's Superior Court in 1972 and 1973, the La Grande project was poorly defined; and in several important respects, differed from the project that was eventually built.

The diversion scheme that was adopted increased the catchment area of the La Grande by roughly 80% - from 97,000 km^2 to 176,000 km^3. In the process, 90% of the flow of the Eastmain and Opinaca rivers (800 m^3/sec) was routed towards the LG-2 reservoir, and 40% of the flow of the Caniapiscau River was routed to LG-4 (770 m^3/sec). Mean annual flow at the mouth of the La Grande has been nearly doubled (3,400 m^3/sec versus 1,750 m^3/sec). By way of comparison, the Churchill-Nelson diversion (the second largest Canadian interbasin transfer) raised the flow of the Nelson (2,830 m^3/sec) by about 25%.

Maximum turbined discharge at LG-2 is 4,300 m^3/sec, roughly equivalent to the pre-diversion mean annual flood; this will rise in the mid-1990's to nearly 6,000 m^3/sec with the construction of a second underground powerhouse. The latter value approximates the 20-year flood of the undeveloped La Grande River. Under present operating conditions, turbined flow remains close to or above the 4,300 m^3/sec level from October to March, and declines to 2,000 m^3/sec before climbing steadily back up during the summer and fall. Thus, late winter flow has been increased by nearly an order-of-magnitude; the spring flood (May-June) has been reduced by about one-half, while flows in October (naturally quite variable) have risen by roughly two-thirds. The pattern just described has been perturbed in the last few years by periodic spillway discharges in spring and fall which have temporarily pushed the total discharge over 6,000 m^3/sec.

The LG-2 powerhouse and forebay were designed in 1974 and 1975 and the other major elements (i.e. LG-3, LG-4, the Caniapiscau and Eastmain reservoirs) were subsequently optimised around the design of LG-2. The location of LG-1 (the powerhouse at the first rapids, which will be built in the next few years) was finally determined in 1978 through a bilateral agreement with Fort George, the community at the mouth of the river (in which process the community was relocated from an island to the south shore, and renamed Chisasibi). Although it had originally been intended that the levels of Sakami Lake (on the diversion route for the Eastmain and Opinaca rivers on their way to LG-2) be kept within their historic range, a bilateral agreement with the community of Wemindji made it possible for the Energy Corporation to avoid the additional costs of excavation at the outlet of this lake (1979).

Originally, the project was designed for an 80% load factor (i.e. the ratio of average to peak turbine output during the year). In 1977-78, the LG-3 and LG-4 powerhouses were redesigned for a 60% load factor, which was taken into consideration in the agreement mentioned above on the relocation of Fort George. Now, in 1988, the addition of a 2,000 MW powerhouse at LG-2 will make it possible to operate the hydro-electric complex as a whole at a 60% load factor, and thus respond with greater sensitivity to weekly and daily changes in load in the Provincial grid.

The choice of design load factor is relevant to environmental impact assessment in several ways. In this case, it affects (because of the changing role of the project in power production across the Province) both the seasonal distribution of flows and the pattern of short-term (daily, weekly) fluctuations. Also important in the case of major interbasin transfers is the effect on peak discharge and its timing. The most dramatic effect of flow regulation in the La Grande is the increase in flow during the five-month period when James Bay is ice-covered, or at least has a fringe of shelf ice. Interbasin diversions, combined with the pattern of regulation just described, raise the volume of fresh water discharged in winter to eastern James Bay by roughly 30 km^3 (from 10 km^3 in pre-diversion conditions). As we shall see later, this raises a number of rather intractable questions about oceanographic impacts in the near-shore and estuarine environment. The imposition, and maintenance, of 20-year flood discharges in mid-winter, combined with rapid changes in water level (in a matter of hours), in some cases of several meters, is also of considerable interest, as we shall also see below. But these are examples of impacts which would have been quite impossible to ascertain 15 years ago, when the project was initially being designed.

SOME ECOLOGICAL ISSUES.

A distinction needs to be made between the ecological impacts of interbasin transfers of water and of hydro-electric development as such. It is the impression of this author that much of the research carried out in connection with river diversions (at least in the boreal forest environment of the Canadian Shield) have chiefly been about hydro-electric development rather than diversions. This was true, to some extent, of the valuable series of studies of Southern Indian Lake in connection with the Churchill-Nelson diversion; impacts on the downstream reaches of the Churchill and Nelson rivers have received very little attention.

In this respect, an examination of the public debate about the environmental impacts of the 'James Bay Project' in the early 1970's can be quite revealing. There was no formal assessment of the La Grande development, although a Federal-Provincial Task Force did survey, in 1971, the rather sparse literature on the James Bay region. But there was a great deal of speculation both about the effects of reservoirs and about the effects of diversions. The effects of suppressing spring floods on river shore-line ecosystems attracted attention, as also did the influence of impoundment and diversion on the regional-scale nutrient budgets of James Bay and Ungava Bay. The significance of transfers of fish and of zooplankton, along with parasites, was also commented upon. But the overwhelming focus of attention was on the sheer extent of flooding (and hence the loss of terrestrial habitat). The reservoirs, after all, have reached a combined total area of over 11,000 km^2, and about 85% of this area was land rather than water before flooding took place. Although this is, in fact, a modest percentage (about 6.25%) of a region in which water occupies 10-15% of the surface area, there was a widespread impression that vast areas of low-lying wetland habitat would be lost. This was the source of genuine concern about the future of hunting and trapping of terrestrial fauna by native peoples, well reflected in the title of the book 'A River Drowned by Water' (Wittenborn and Biegert, 1981).

There was concern, as well, about the effects of the diversions, and this was directed primarily at the fate of the communities of Eastmain and Kuujuuaq (at the mouths of the Eastmain/Opinaca and Caniapiscau/Larch river systems, respectively). The reduction in habitat in these diverted rivers, together with loss of freshwater input to their estuaries, was perceived as a serious threat to the domestic or subsistence fisheries of these communities. Eastmain, in particular, was singled out as particularly vulnerable, both because of the extent of flow reduction (90%) and the scale of flooding of the inland Eastmain traplines.

Fort George, at the mouth of the La Grande, was supported, like Eastmain, by a local fishery based on anadromous whitefish, cisco and trout. Here, too, there was concern about the impacts of the project on fisheries resources. The emphasis, however, was on the loss of traditional fishing grounds at the first rapids (the site of LG-1, still to be built), and the effects of cutting off the flow of fresh water during the filling of LG-2. There was to have been flow maintenance during the filling of this reservoir, but this too became the subject of a bilateral agreement with the Fort George Crees - and, in the event, there was no flow maintenance. Concern was also expressed about the longer-term effects of erosion on the island where the Fort George Band was then located, and about possible effects of reduced nutrient supply on the sea-grass (zostera spp.) beds along the James Bay coast.

Many of these concerns - inevitably, in the absence of supporting documentation - were expressed in very general terms, although there was widespread consensus about their validity. These concerns, however, have not really been reflected in subsequent research programmes, although Berkes' series of studies of the evolving subsistence fishery at Chisasibi (e.g. Berkes, 1985) and Weinstein's survey of the inland economy at Chisasibi in 1973-74 (Weinstein, 1976) are important exceptions.

The merits of flow maintenance were debated; and an initial undertaking to use 2% of the annual flow of the Eastmain at the point of diversion as a basis for flow maintenance during two months of the year is to be found in the 1974 Agreement-in-Principle (Entente-en-Principe, 1974). This approach was eventually abandoned, and the credit of (1974) $13 million was subsequently used to finance a remedial works corporation (SOTRAC) with general responsibilities for such activities below the points of diversion. Indeed, this concept of remedial works, integrated into the James Bay and Northern Québec Agreement, has come to reflect a policy of both the Energy Corporation and Hydro-Québec whereby undesirable impacts, once apprehended, are 'mitigated' by measures aimed at removing the source of impact or involving other forms of support for the subsistence use of wildlife by the affected Cree families. The classic case was the re-impoundment of sections of the Eastmain and Opinaca rivers to restore original water levels and abate turbidity.

ECOLOGICAL MONITORING

There was no formal assessment of the impacts, social or environmental, of the La Grande Complex - at least in the sense in which we now talk of impact assessment. Indeed, the project arrived seven years before the adoption under Québec law of a formal assessment procedure. In some respects, however, the hearings for an injunction against the initial development provided a forum for the airing of views that might be found in an impact statement and an occasion for some field research (Penn, 1975).

The controversy surrounding the project in its early days, and the unwelcome publicity of litigation, nevertheless served as a powerful incentive for the James Bay Energy Corporation to respond to its critics. This it did in three ways. First, it was a signatory of the James Bay and Northern Québec Agreement, and participated actively in its negotiation; this made it possible to use the Agreement for the formal approval, with respect to environmental considerations, of the project, and put in place an institutional framework for planning and executing remedial measures. Second, the Corporation formed an advisory committee on environmental policy, composed mainly of senior executives of the Corporation, heads of consulting firms involved in environmental studies related to the project, and consultants named by the Cree, the Inuit and later, the Naskapi. Third, the Energy Corporation embarked upon a policy of monitoring certain physical and biological impacts and of preparing sectorial impact statements for the later components of the hydro-electric project. The studies carried out under this policy provided much of the material discussed by Roy and Messier in their presentations.

The cornerstone, one might say, of this policy was the Réseau de Surveillance écologique (Ecological Monitoring Network). This was, in its essential features, a programme of observation of changes in water quality and biota in the LG-2, Caniapiscau and Eastmain/Opinaca sectors of the La Grande complex. Lakes in areas later subject to flooding provided one or two years of information on pre-flooding conditions; and observations continued after impoundment. In its original form, the programme spanned the period 1978 to 1984. Responsibility for the programme has now been assumed by Hydro-Québec, which is currently engaged in a two-year (1987-88) survey of the complex as a whole. Discussions are currently under way to determine objectives and a suitable organizational framework for longer-term monitoring of the evolving environment of the reservoirs (Hydro-Québec/Cree Regional Authority, 1988).

The Ecological Monitoring Network included a range of standard limnological observations of water chemistry as well as surveys of fish (catch per unit effort; age and size by species), zooplankton by major group and an effort to survey benthic macroinvertebrates. Some of the data was incorporated into simulations of reservoir ecology (Thérien, 1981). The fish were also used for mercury analysis, thus furnishing a large set of data on mercury concentrations before and after impoundment (and, incidentally, an incentive to pursue such surveys in the future). The programme included the rivers subject to changes in flow, as Roy and Messier explain.

Monitoring along these lines has undoubtedly contributed to our general understanding of evolving aquatic ecosystems; and a number of complementary studies have responded to questions raised about the estuarine environment, changing shorelines, bank stability and slope development, and about terrestrial fauna. One may query some aspects of these investigations, but the overall conclusion is that the Energy Corporation's initiative in these areas has been widely appreciated - and, in many cases, it is the only source of information available. Very little, if any, government-sponsored research has been carried out in the region independently of the Corporation.

Thus we can conclude, for example, that the absence of large-scale oxygen depletion in reservoir waters, and relatively slight changes in major ion chemistry have meant that inter-basin diversions have not been accompanied by evident deterioration in water quality. We remain comparatively ignorant about nutrient budgets in the reservoirs and rivers of the region, and along the coast of James Bay itself. We have some indices, though, in the form of chlorophyll alpha and total phosphorus concentrations, which suggest the order-of-magnitude of changes in primary productivity after impoundment. Catch-per-unit-effort information for fish (supplemented with age/size relationships) make it possible to document the expanding fish stocks in the reservoirs and argue the case for recovery or adaptation of stocks after the filling of the LG-2 reservoir or the diversion of the Eastmain river. Monitoring of the aquatic environment, at least at first sight, offers a reassuring view of responses of water quality to river diversion.

This is not the full story, however. A number of changes have taken place which were not anticipated when the Network was designed. One of them is the increase of mercury levels in fish post-impoundment. Although there are some uncertainties in the data base, we can say that LG-2, the Eastmain/Opinaca reservoir, and the diversion route linking the two have been the scene of an initial four to five fold increase in mercury levels in fish. This is about the same order as the normal difference between predatory and non-predatory species of fish, and has made an appreciable difference to human levels of exposure in families fishing on the reservoirs. The phenomenon is receiving considerable attention, but there is much that remains unclear. It does appear, however, that the problem may be less acute in headwater reservoirs and forebays, and that there are significant downstream effects (notably in the La Grande River below LG-2). Rivers subject to reduced flow remain largely unaffected, but in the coastal environment, there are indications (Roy, personal communication) that measurable increases in mercury concentrations coincide broadly with the geographical extent of the winter plume of the La Grande river. It is clear, as well, that the rapid evolution of the fish populations themselves means that there is considerable variation in mercury concentration both within and between fish species.

Another topic that has attracted attention in the last few years is that of eel-grass beds and the environmental factors which govern their distribution. The stimulus here came from the impact assessment studies carried out by the Energy Corporation in connection with the planning of the second powerhouse at LG-2. Eel-grass beds in James Bay have long been perceived as important in the migration of waterfowl along the Atlantic flyway. Particularly in the case of the brant, eel grasses seemed to play a major role in meeting the energy requirements for migration. When it appeared, a few years ago, that the eel-grass beds had thinned or disappeared along sections of the James Bay coast, the La Grande project was immediately suspect. At the time, it seemed that the sea grasses were no longer to be found where winter salinities fell below five ppt. This, in turn, meant that the additional winter discharge following the building of the second powerhouse at LG-2 might be accompanied by further declines in the eel grass beds along the coast. The Energy Corporation has subsequently undertaken much more complete surveys of the eel grass beds as well as detailed investigation of distribution of salinity and water temperatures along the complex, indented coastline of James Bay. These surveys (Messier, personal communication) reveal a much more complex pattern both of eel grass distribution and of mixing processes along the James Bay coast. The initial concern may prove to have been exaggerated; however, we now know much more than we did five years ago about the physical oceanography of the James Bay coast in winter and its relation to littoral ecosystems. It is worth noting, however, in this case that it was the Energy Corporation that identified and responded to this apparent impact (with input from the regional native organizations); such assessment as has been made has taken place largely without the input of the Canadian Wildlife Service - a reflection of the weakness of the institional mechanisms available in Northern Québec for securing the involvement of government research agencies in issues of impact assessment or monitoring.

When the LG-2 reservoir was being filled, advantage was taken of the reduced flow downstream to build the coffer dam required for the construction of LG-1. The hydraulic capacity of the diversion channel that was then built was smaller than the discharge from the turbines at LG-2. One of the consequences, therefore, was a general increase in water levels upstream from LG-2. This, accompanied by wave action and the sloughing of perched ice platforms in a situation of frequent fluctuation in water levels, has made the river banks much more active, especially along the north shore of the river. Matters were brought to a head, so to speak, in September of 1987 when a flowbowl with an area of more than 12 ha deposited about 3.0 million m^3 of fine sediment into the channel of the La Grande as well as a number of trees. Erosion and the factors governing bank stability have become, in the space of a year or two, a significant preoccupation; and survey monuments have now been put in place to monitor future changes. Fifteen years ago, there was a debate, albeit rather unfocussed, about the effect of changes in the flow régime of the La Grande River on slope development; now we are beginning to see what is happening and attention has been directed to the evaluation of stability criteria and the role of different factors in sediment removal.

We can learn, as well, from the experience of monitoring the Eastmain and Opinaca rivers below their respective points of diversion. The diversion resulted in a lowering of water levels, sometimes by several meters, and the exposure of the old river beds. As in the case of the La Grande, the river valleys were developed in silt-rich post-glacial marine clays. Gullies formed, and erosion resulted in turbidity, visible from the air. This was an example of a visual impact; measured concentrations (up to roughly the 50 mg/l mark) of suspended sediment were not, in themselves, dramatic. The result was the construction, by the Energy Corporation and the remedial works corporation, of four weirs designed to restore original water levels. The merits, and the costs, of such interventions were hotly debated, and many studies were produced. The fact remains that these weirs were controversial. They had the anticipated effect of reducing turbidity, and they created a series of ribbon-like lakes with short residence times. If they had not been built, the valley floors would have been recolonized by grasses and shrubs in a few years. Probably, a comparatively rich valley-bottom vegetation would have developed, with good potential for a number of species of animal hunted or trapped by the Cree.

The case is interesting because it enables us to see the interplay of a number of different perceptions of environmental values - those entertained by the Energy Corporation, and those of the residents of the community of Eastmain. Each viewed this type of remedial measure with some ambivalence, but for different reasons. In the final analysis, however, the same question kept recurring - by what criteria can we evaluate the relative merits of the terrestrial habitat created by not intervening and the aquatic habitat resulting from the building of the weirs. There were no simple answers.

RESEARCH NEEDS AND RIVER DIVERSIONS:
REFLECTIONS IN THE LIGHT OF THE LA GRANDE COMPLEX

What does the La Grande Complex tell us about research needs in connection with the interbasin transfers of water? The answer depends partly on the time-scales which we assume to be appropriate for the monitoring of environmental impacts; it also depends on the type of interbasin transfer we expect to face in the foreseeable future.

In Northern Québec, we have detailed knowledge of future diversions. The principal uncertainty is the time frame for their realisation. The Great Whale Complex involves an inter-basin diversion in some respects analogous to the Caniapiscau-La Forge diversion described by Roy in his paper (the Little Whale-Boutin-Great Whale diversion). It also involves the diversion of the combined flow of these rivers into the Manitounuk Sound north of the communities of Kuujuaraapik and Whapmagoostui. Evaluating the impacts of a major freshwater discharge into this essentially marine basin (including the transfer of mercury) will undoubtedly feature prominently in the assessment of this project. The Nottaway-Broadback-Rupert diversion further south is much more complicated and may eventually involve eleven forebays/powerhouses and four major reservoirs for storage and interbasin transfer. Much of the engineering work, including the extensive network of dykes and diversion channels, would have to be carried out in the soft clays of the pro-glacial lake Barlow-Ojibway. Reservoirs would be generally shallow, and large expanses of reservoir bed would be exposed during draw-down.

Both of these schemes involve substantial changes in the location of freshwater inputs to the marine environment, and their timing. Salinity in shallow coastal waters will drop, especially during the winter months. Fluxes of nitrogen and phosphorus in coastal ecosystems can reasonably be expected to change, as well as the role of primary production at the ice/water interface. Much of the concern expressed so far about impacts in the marine environment has focussed on the sea-grasses - because of their relation to the migration of waterfowl, and because their distribution, in this region, seems to be influenced by salinity (although the effects of ice-scour during onshore storms in spring and early summer may prove to be even more important).

The La Grande Complex provides a 'natural experiment', one might say, where hypotheses dealing with impacts of hydro-electric development on coastal ecosystems can be formulated and tested. Progress is being made in determining more precisely the distribution of the eel grass beds, and this work, combined with winter surveys of currents, temperature and salinity will shed light, in the next few years, on the respective roles of salinity and shore ice in the sea-grass ecosystems. Much remains to be learned, however, about the structure of the sea-grass ecosystems and their importance both for the fish populations of the James Bay coast and for waterfowl migration. We know comparatively little about nutrient inputs to the estuarine and coastal environments of James Bay, and the role of sea-grasses in nutrient cycling. How far do the obligations of Hydro-Québec or the James Bay Energy Corporation extend in such a case? So far, this question has been answered with the argument that the proponent's responsibilities are confined to the essentially descriptive work of monitoring changes in readily-observed variables that can be used to characterize the evolving environment. This author would argue further that questions about environmental impact, in such a case, require an understanding of the structure and functioning of ecosystems that we do not possess at the present time. This, in turn, implies a research agenda that goes well beyond the normal responsibilities of the proponent, and should involve the government agencies which are, in the final analysis, responsible for authorizing such development. Unfortunately, the La Grande development has so far been distinguished by the almost complete absence of such involvement.

A similar set of arguments can be developed for the anadromous stocks of trout, whitefish and cisco along these coasts, about which we know very little. They support a domestic coastal fishery in the five Cree coastal communities; there is some biological evidence of the pressures of exploitation for the domestic fishery; there is a tendency for stocks to 'home' on a particular river. Current work on the biochemical genetics of some of these stocks may help to answer questions about homing; and studies of the physiological ecology of anadromous whitefish shed some light on responses to sharp reduction in flow (see chapter by Morin and Dodson in Martini, 1986). But the major weakness lies in our ability to anticipate the effects on over-wintering anadromous fish of very large increases in winter flow, such as we now associate with the La Grande river. We are unable to explain whether fish can maintain station in winter under these conditions, or whether they are displaced towards the coast. If they do move out in the fluctuating environment of the winter plume, are they trapped in water of steadily rising salinity and lower temperature? We don't know, and there is little in the current programme of studies of the James Bay Energy Corporation that will shed light on this question. Similarly, the eggs and fry of fall-spawners in the La Grande may be swept out to the coast under conditions or rising discharge in October and November. It is too early to tell on the basis of the last two or three years of project operation, but monitoring of the age structure of the whitefish and cisco populations will, at least, enable us to see whether failures of recruitment take place under a specified range of future flow conditions. Here again, the question of the extent of the proponent's obligation arises; monitoring of catch per unit effort will yield information about trends in yield and about age structures; but there are important practical limitations to the kind of information such surveys can provide about the relation between river hydraulics, estuarine dynamics and life history. Should there not be an attempt to acquire a more fundamental understanding of the responses of anadromous fish to such changes in river hydrology?

Enhanced methyl mercury bio-accumulation in fish is not,strictly speaking, an impact arising from interbasin diversions. But the freshwater plume in the river that receives the diverted flow (particularly in situations of a winter ice-cover in the coastal environment) is a potential vehicle for the transfer of mercury to coastal ecosystems. Indeed, the investigation of mercury cycling in the coastal environment provides an example of a theme which links studies of physical oceanography with investigations of the life histories of coastal fish populations. And it provides another example of the problem of defining the limits of ecological monitoring and its relation to more fundamental research.

Transfers of parasites and of new fish species received little attention in the studies of the La Grande Complex (although, as Roy points out, there is some evidence that ouananiche are moving into the La Grande watershed from the Caniapiscau basin). Should there be more emphasis on the screening of parasites and other factors which affect the quality of fish in reservoirs? The experience with the whitefish fishery in Southern Indian Lake would lead one to think so (Bodaly et al. 1984).

This brings me, finally, to the geomorphology of river valleys subject to major increases in discharge. In the case of the La Grande, there has been a long and not particularly fruitful debate about the concept of a 'dominant' discharge and what that might be in this particular case. It has proved to be an intractable question. Thus far, even with discharge in excess of 4,000 m^3/sec (i.e. roughly equivalent to the former mean annual flood), the silty clays of the Tyrrell sediment which form the river bed retain their cohesion; there is no major rise in turbidity or suspended sediment which suggests that the bed is losing its armouring of cobbles or that the cohesion of the sediment is changing. Will this remain true when the discharge rises to 6,000 m^3/sec? It is hard to say; accurate monitoring of cross-sections of the river at selected stations would be needed to answer this question.

Although the bed of the La Grande may remain fairly stable, the banks are certainly not. Daily changes in water level, combined with freeze-thaw cycles in winter and the action of waves and currents, have created a geomorphologically active environment that is plain to all. Ribbons of turbid water flank the exposed slopes, and fresh flow bowls are frequent above LG-1. Theses banks, where the most spectacular slides have taken place, will probably be flooded (typically to depths of 10-15 m) when the LG-1 forebay is flooded (in perhaps eight to ten years' time). Flooding may have the effect of suppressing bank erosion, at least to the extent that a smaller amplitude of diurnal water level changes will reduce the rate of removal of material. Nevertheless, we can expect the La Grande valley above LG-1 to continue to evolve for a number of years.

But the construction of LG-1 will have the effect of transferring downstream the zone of rapidly fluctuating water levels. Under existing conditions, the riparian vegetation between LG-1 and the community of Chisasibi some 25 km downstream is gradually being removed by ice and currents. In the future, the exposed shores will be subjected to essentially the same processes that we now observe further upstream - although perhaps not at the same rates. The longer-term significance of this bank evolution is unclear. Chisasibi itself was built ten years ago on the bluffs overlooking this river, and protective berms of large cobbles have been put in place to protect the community from erosion by the river.

The magnitude of the changes in river flow régime, in this author's opinion, make this a particularly valuable opportunity for evaluating the relationship between managed flow régimes and geomorphological controls of river bed and river valley development. There is probably no other example of such a transformation of a flow régime, which makes the La Grande rather unique. But the experience acquired from monitoring this river valley will have direct application to the Nottaway - Broadback Rupert development further south and perhaps to other diversions in Canada. More particularly, it is relevant to the residents of the community of Chisasibi (pop. 2,500) at the mouth of the river. Again the problem arises, however, of defining the extent of the proponent's responsibility for monitoring.

These examples illustrate the potential importance of monitoring environmental changes induced by hydro-electric development over the longer term. In each case, we can expect that a period of ten or even twenty years will be needed for an adequate description - a time-frame partly dictated by the fact that the project itself will not be complete for another ten years. But there is much more to this than a long-term commitment to monitoring. If we do not learn more about process, about the functioning of northern ecosystems, some of the effort put into monitoring will have been wasted. The La Grande Complex provides numerous examples of areas where more fundamental research is needed - but, at the same time, research with a practical orientation. Both Provincial and Federal government departments with an interest in the issues discussed here need to re-evaluate their presence in the region, and the policies which dictate the resources allocated to research relevant to northern hydro-electric development.

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RÉPERCUSSIONS DU TRANSFERT DES EAUX DES RIVIÈRES EASTMAIN-OPINACA ET CANIAPISCAU DANS LA GRANDE RIVIÈRE (QUÉBEC)

D. ROY[1] ET D. MESSIER[1]

RÉSUMÉ

Le débit de La Grande Rivière a pratiquement doublé grâce à la dérivation des eaux des rivières, Eastmain et Caniapiscau. On a aussi optimisé la production hydroélectrique en obturant des exutoires mineurs des lacs Frégate et Vincelotte. Les rivières dont le débit a été ainsi augmenté coulent dans des matériaux peu érodables; fait exception La Grande Rivière où on rencontre, le long de son parcours, de l'argile marine et des sables silteux. Les volumes de matériaux entraînés sont plus importants sur cette dernière à cause de la taille du cours d'eau, de la sensibilité des matériaux de la rive et des variations de niveau. La grande stabilité de la qualité de l'eau dépend de l'origine commune des eaux des trois rivières et de l'aération qui s'effectue à la sortie des réservoirs. Les organismes planctoniques ont peu réagi à l'augmentation des débits. La Grande Rivière abritait déjà les espèces de poissons rencontrées dans les rivières Eastmain et Caniapiscau, à l'exception de la ouananiche (Salmo salar) qui ne pourrait être qu'une introduction souhaitable. Les hausses de mercure observées dans ces parcours ne sont pas le résultat des dérivations mais sont plutôt dues à l'entraînement vers l'aval de l'eau et des organismes contaminés dans les réservoirs.

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INTRODUCTION

La réalisation du Complexe La Grande a nécessité l'aménagement, pour fins de production hydroélectrique, de La Grande Rivière dont on a doublé le débit par la dérivation des eaux de deux rivières adjacentes, la Eastmain et la Caniapiscau (Figure 1). Il y eut de plus réorganisation du système hydrographique en limitant à un seul exutoire les eaux qui s'écoulaient auparavant des lacs Frégate et Vincelotte. Messier et Roy (1987) ont donné un aperçu des effets de la réduction de débit en aval de certains ouvrages de génie. Nous nous attarderons ici aux répercussions observées dans les tronçons de rivières et dans les lacs soumis à des augmentations ou à des régulations de régime.

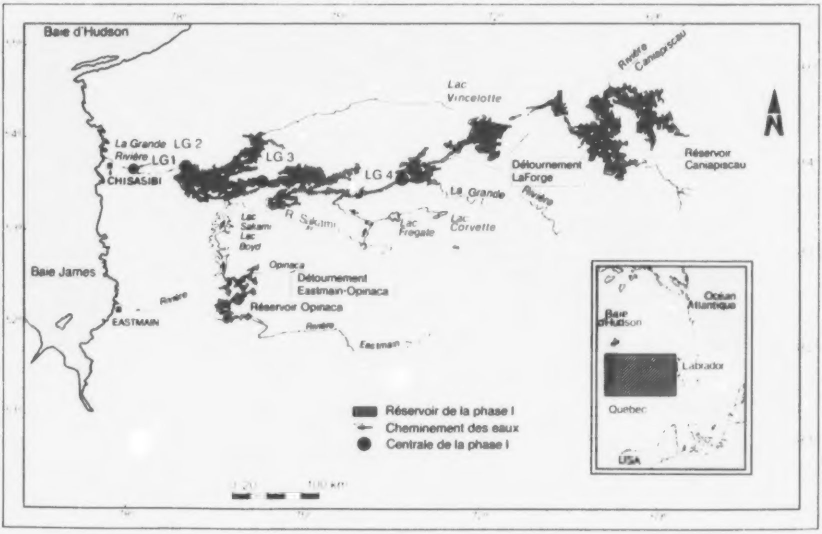
Baie d'Hudson
Rivière Caniapiscau
Lac Vincelotte
La Grande Rivière
LG 2
LG1
CHISASIBI
LG 3
LG 4
Détournement LaForge
Réservoir Caniapiscau
La Grande Rivière
Lac Sakami
Lac Boyd
R. Sakami
Lac Fregate
Lac Corvette
Baie James
Opinaca
Détournement Eastmain-Opinaca
Réservoir Opinaca
Rivière
EASTMAIN
Rivière Eastmain
Réservoir de la phase I
Cheminement des eaux
Centrale de la phase I
0 20 100 km
Océan Atlantique
Baie d'Hudson
Labrador
Quebec
USA

Figure 1. Le complexe hydroélectrique La Grande.

CARACTÉRISTIQUES DES TRONÇONS

Les deux sections les plus sérieusement touchées se trouvent entre le réservoir Opinaca et celui de La Grande 2 et entre le réservoir Caniapiscau et celui de La Grande 4. Les eaux détournées de la rivière Eastmain et de deux de ses affluents, les rivières Opinaca et Petite rivière Opinaca (810 $m^3.s^{-1}$), empruntent tout d'abord une vallée où ne coulait auparavant qu'un ruisseau et traversent par la suite le lac Sakami. Cette dérivation, la première en opération, a fait l'objet de nombreuses études de suivi et les observations ont été consignées dans plusieurs rapports produits par ou pour l'entreprise (SOGEAM Inc., 1983; Schetagne et Roy, 1985; Roy, 1985; Boucher et Roy, 1987).

Le tiers supérieur du bassin de la rivière Caniapiscau et environ 40% de son débit initial apportent maintenant un complément de 776 $m^3.s^{-1}$ au débit de La Grande Rivière. Ces eaux sont surtout fournies en hiver, période où les besoins du système sont les plus urgents. Après avoir emprunté le cours de deux petites rivières du bassin de la Grande rivière à la Baleine, les eaux rejoignent la rivière Laforge, un affluent mineur de La Grande Rivière. C'est à la sortie du lac Vincelotte que la rivière du même nom a été partiellement bloquée permettant ainsi à la rivière Laforge d'écouler la presque totalité des eaux vers le réservoir de La Grande 4. Des digues accessoires ont dû être ajoutées de part et d'autre du trajet afin de restreindre, en un couloir relativement étroit, le parcours des eaux. En effet, la turbulence des eaux maintient à certains endroits des zones ouvertes qui engendrent, au contact de l'air froid, des volumes de frasil importants. Les niveaux d'eau alors surélevés auraient pu permettre à l'eau de passer d'un bassin secondaire à un autre et même de revenir dans celui de la Grande rivière de la Baleine. Ce parcours des eaux de forme anastomosée aurait été difficile à gérer et il aurait augmenté les répercussions environnementales. Un suivi portant sur l'écoulement des eaux, l'érosion, la sédimentation, la qualité des eaux et la concentration de mercure des poissons a été mis sur pied mais la période relativement courte d'opération de cette dérivation n'a pas généré une connaissance aussi complète que pour le détournement Opinaca-La Grande.

La rivière Sakami avait un trajet capricieux. Après un parcours est-ouest parallèle à La Grande Rivière, elle avait été captée presque complètement par la rivière Corvette et coulait surtout vers le nord, rejoignant La Grande Rivière là où se trouve maintenant le réservoir de La Grande 3. Le débit dans l'ancien lit du cours inférieur de la rivière Sakami était contrôlé par le niveau des eaux dans la région du lac Frégate; le cours inférieur agissait comme un évacuateur de trop plein et subissait des variations de débit de 1 à plus de 700 $m^3.s^{-1}$. Une digue a permis de diriger toutes ces eaux directement vers la centrale de La Grande 3 et ainsi profiter d'une plus grande puissance à ce point. Les répercussions causées par cette augmentation de débit ont plutôt été restreintes car le lit et les rives de la rivière Corvette sont formés de gravier et de blocs grossiers.

À partir du réservoir de La Grande 4 jusqu'à celui de La Grande 2, La Grande Rivière est une suite de réservoirs adjacents et les effets de l'augmentation de débit se font peu sentir. Cependant, une distance de 112 km sépare La Grande 2 de l'embouchure de cette rivière dont 37 km peuvent être affectés par la marée lorsque les débits sont relativement faibles. Dans ce tronçon, le module annuel de La Grande est passé à 3400 $m^3.s^{-1}$ soit le double du module antérieur, et le débit hivernal a presque décuplé par suite de la régulation pour la production hydroélectrique. Afin de bien évaluer les répercussions pouvant toucher les habitants du village de Chiasibi situé près de l'embouchure et les stocks de poissons qu'ils exploitent, des études et des suivis intensifs ont porté sur l'hydraulique et le régime des glaces (SEBJ et Laboratoire d'hydraulique

La Salle Ltée, 1984), sur la géomorphologie des rives (Lupien, Rosenberg, Journeaux et Ass., 1984) ainsi que sur la qualité des eaux et la dynamique des populations des poissons anadromes en aval de La Grande 2 (Boucher et al., 1984). Les modifications sur l'ampleur et la structure du panache des eaux douces dans la baie James ont aussi été notées et consignées dans Messier et al. (1986).

Afin de restreindre l'ampleur de cette communication, nous nous limiterons au parcours des eaux de la rivière Eastmain, du réservoir Opinaca vers celui de La Grande 2, ainsi qu'au tronçon non encore aménagé en aval de La Grande 2.

MATÉRIEL ET MÉTHODES

Le long de la dérivation des eaux de la rivière Eastmain vers La Grande Rivière, 3 stations du réseau de surveillance écologique de la Société d'énergie de la Baie James (SEBJ) ont permis de suivre l'évolution de la qualité de l'eau, de l'abondance du plancton et du comportement des poissons. Celle dite d'Opinaca, est située à quelques kilomètres de l'exutoire du réservoir Opinaca. Celle du lac Sakami se trouve à mi-chemin de la dérivation alors que la station Coutaceau, sise à l'entrée du réservoir de La Grande 2, rend compte de la contribution de la rivière Sakami. L'érosion et la sédimentation ont été suivies grâce à de nombreux points d'observation répartis tout le long du parcours. Enfin, les inventaires effectués sur la faune (castor, orignal, sauvagine) ont permis de mesurer les changements, s'il y en avait.

Pour quantifier les modifications observées dans La Grande Rivière, en aval du réservoir de La Grande 2, il est possible d'utiliser une ou plusieurs des 6 stations du réservoir de La Grande 2 et les 2 exploitées dans la rivière, l'une en amont du premier rapide et l'autre à son embouchure.

L'échantillonnage de la qualité de l'eau et du zooplancton a été effectué, de 1978 à 1974, à toutes les 2 semaines pendant la période libre de glaces. De plus en période hivernale, 4 prélèvements d'eau étaient généralement recueillis sous la glace. Les pêches suivaient une fréquence mensuelle entre les mois de juin et octobre. Le suivi de l'érosion des rives et du transport des particules en suspension dans l'eau fut plus irrégulier, variant de quelques observations à plus d'une quinzaine par année, suivant les besoins.

Les paramètres observés et les méthodes d'analyse en laboratoire sont suffisamment décrits dans Messier et Roy (1987). Les données vérifiées sont conservées dans la banque de données écologique de la SEBJ.

LE PARCOURS OPINACA - LA GRANDE 2

Un module annuel de 810 $m^3.s^{-1}$ est prélevé du réservoir Opinaca. Comme seulement un maximum de 1980 $m^3.s^{-1}$ peut être évacué à l'ouvrage de contrôle, le surplus est accumulé dans le réservoir et constitue une réserve de 3,4 Gm^3. Ce volume est ensuite utilisé en hiver au moment où les apports naturels sont très faibles; le débit minimal prévu se situe autour de 740 m^3.s^{-1}. C'est donc une rivière importante qui traverse tout d'abord un grand lac (Boyd) et rejoint le lac Sakami en empruntant la vallée de son émissaire. Des prévisions de formation de glace dans ce tronçon ont conduit à l'installation de deux petites digues latérales et au déboisement, pour fins hydrauliques, de quelques sections des rives.

Tableau 1. Qualité de l'eau (1978-1980) de quelques pièces d'eau qui seront dans le trajet de la dérivation des eaux de la rivière Eastmain vers La Grande Rivière et la baie James; les nitrates étaient ordinairement sous le seuil de détection de 0,02 mg/L.

	Région Opinaca	Lac Sakami	Lac Coutaceau	La Grande Rivière
Couleur (unités Hazen)	36	28	36	23
Turbidité (UTN)	1,1	0,9	1,8	2,5
Transparence (m)	2,1	3,2	2,0	2,4
Température max. (°C)	17,5	15,0	15,0	16,0
O_2 dissous (mg/L)	10,2	10,5	10,9	11,7
Saturation O_2 (%)	97	95	100	105
pH (unités)	6,2	6,6	6,6	6,5
Conductivité (µS/cm)	13	18	17	14
Chlorures (mg/L)	0,4	0,7	0,4	0,3
Bicarbonates (mg/L)	2,4	3,8	4,1	4,0
Sulfates (mg/L)	3,0	3,0	3,0	2,7
Sodium (mg/L)	0,6	1,3	1,2	0,9
Potassium (mg/L)	0,3	0,5	0,4	0,3
Magnésium (m [illegible]	0,3	0,5	0,5	0,4
Calcium (mg [illegible]	1,0	1,2	1,2	1,3
Fer total (mg/L)	0,26	0,12	0,18	0,21
Azote Kjeldahl (mg/L)	0,12	0,13	0,19	0,15
Phosphore total (µg/L)	8	7	11	13
Carbone inorganique total (mg/L)	0,7	1,0	1,0	1,1
Carbone organique total (mg/L)	8,2	8,2	7,9	6,2
Silice (mg/L)	2,3	2,2	2,1	2,4
Tanins (mg/L)	1,3	1,1	1,3	1,1
Chlorophylle α (µg/L)	1,26	1,21	1,92	1,46
Phéopigments (µg/L)	0,72	0,45	0,56	0,54

L'augmentation du débit transitant dans le lac Sakami a provoqué une hausse du niveau des eaux de 3 mètres au-dessus des niveaux antérieurs. Il aurait été trop coûteux de modifier la géométrie de l'exutoire du lac Sakami afin de le contenir à l'intérieur des limites des variations naturelles. Il a donc fallu procéder à la négociation d'une entente avec les autochtones afin de modifier un article de la Convention de la Baie James et du Nord Québécois de 1975.

Tableau 2. Qualité de l'eau de surface (0-10 m) observée la seconde année (1981) du détournement des eaux de la rivière Eastmain dans La Grande Rivière et la baie James; les nitrates étaient ordinairement sous le seuil de détection de 0,02 mg/L.

	Région Opinaca	Lac Sakami	Réservoir LG 2	La Grande Rivière
Couleur (unités Hazen)	38	39	32	28
Turbidité (UTN)	0,8	3,4	1,4	1,3
Transparence (m)	2,3	1,5	2,5	2,2
Température max. (°C)	19,2	16,8	18,2	15,5
O_2 dissous (mg/L)	8,6	10,4	9,6	12,2
Saturation O_2 (%)	77	90	81	98
pH (unités)	6,1	6,2	6,4	6,4
Conductivité (µS/cm)	13	14	17	17
Chlorures (mg/L)	0,5	0,6	0,6	0,6
Bicarbonates (mg/L)	2,8	3,2	4,5	4,3
Sulfates (mg/L)	1,1	1,6	1,1	1,3
Sodium (mg/L)	0,6	0,8	0,9	0,8
Potassium (mg/L)	0,4	0,6	0,6	0,5
Magnésium (mg/L)	0,3	0,4	0,4	0,4
Calcium (mg/L)	1,2	1,2	1,5	1,3
Fer total (mg/L)	0,16	0,24	0,20	0,16
Azote Kjeldahl (mg/L)	0,17	0,17	0,19	0,13
Phosphore total (µg/L)	16	15	14	12
Carbone inorganique total (mg/L)	1,4	1,5	1,9	1,7
Carbone organique total (mg/L)	6,8	6,9	6,2	5,4
Silice (mg/L)	2,2	2,5	1,6	1,8
Tanins (mg/L)	1,2	1,2	1,0	0,8
Chlorophylle α (µg/L)	2,18	2,14	2,32	1,74
Phéopigments (µg/L)	1,06	0,85	0,87	0,50

On a appréhendé d'importants remaniements de matériaux des rives soit par l'érosion des rives et du lit de la rivière Boyd, soit par l'accumulation des matériaux érodés dans les sections lentes. Après 5 ans d'observation, on n'a noté qu'une zone d'érosion importante en aval du rapide le plus près du lac Sakami. Ce glissement de matériaux morainiques a été particulièrement actif en 1981, la première année complète du détournement des eaux. Un dallage de blocs provenant du lessivage des matériaux éboulés est rapidement venu protéger la base des talus et limiter la profondeur de la zone érodée. La longueur de cette rive sensible est de 12 km et les volumes entraînés dans la rivière furent de 55 000 m^3 et de 4 000 m^3 en 1981 et 1982. Le fond de la rivière s'est aussi érodé. On estime le volume des sédiments enlevés à environ 55 000 m^3, en 1981 et en 1982; d'après la turbidité enregistrée, le phénomène a semblé diminuer par la suite. Cela correspondrait à une couche moyenne d'un ou deux cm de sédiments fins que le courant aurait enlevés du fond chaque année. La nature des matériaux morainiques et la protection apportée par la végétation terrestre submergée et les dépôts organiques des tourbières ont limité l'attaque par la vague le long de la rivière et sur les rives des lacs Boyd et Sakami.

Tableau 3. Qualité de l'eau de surface (0-10 m) observée la cinquième année (1984) du détournement des eaux de la rivière Eastmain dans La Grande Rivière et la baie James; les nitrates étaient ordinairement sous le seuil de détection de 0,02 mg/L.

	Région Opinaca	Lac Sakami	Réservoir LG 2	La Grande Rivière
Couleur (unités Hazen)	40	34	28	24
Turbidité (UTN)	1,1	1,6	1,0	1,5
Transparence (m)	2,1	1,9	2,6	2,5
Température max. (°C)	18,1	17,0	17,6	12,0
O_2 dissous (mg/L)	9,1	10,0	9,9	11,5
Saturation O_2 (%)	85	92	88	96
pH (unités)	6,2	6,3	6,4	6,4
Conductivité (µS/cm)	12	13	14	14
Chlorures (mg/L)	0,4	0,5	0,5	0,4
Bicarbonates (mg/L)	2,2	2,3	3,4	3,4
Sulfates (mg/L)	2,0	2,0	1,6	1,6
Sodium (mg/L)	0,6	0,7	0,8	0,8
Potassium (mg/L)	0,3	0,4	0,4	0,4
Magnésium (mg/L)	0,3	0,3	0,4	0,3
Calcium (mg/L)	1,0	1,1	1,3	1,2
Fer total (mg/L)	0,22	0,19	0,17	0,20
Azote Kjeldahl (mg/L)	0,19	0,18	0,18	0,16
Phosphore total (µg/L)	16	12	11	12
Carbone inorganique total (mg/L)	1,3	1,0	1,5	1,4
Carbone organique total (mg/L)	6,7	6,5	5,3	5,8
Silice (mg/L)	1,9	2,1	1,0	1,1
Tanins (mg/L)	1,1	1,0	0,8	0,7
Chlorophylle α (µg/L)	2,11	2,61	2,42	1,18
Phéopigments (µg/L)	1,42	1,59	1,59	1,18

Les eaux des rivières Eastmain et Opinaca étaient légèrement plus acides, plus organiques et moins riches que celles de La Grande Rivière et des lacs de la région de La Grande 2; elles étaient presque identiques à celles de la région de La Grande 3 ou 4 (Tableau 1). La qualité de l'eau dans le lac Sakami est devenue, avec le temps, semblable à celle du réservoir Opinaca sauf pour quelques paramètres qui ont été modifiés par l'aération dans les sections de rivière turbulentes ou par la mise en suspension des matériaux arrachés aux rives (Tableaux 2 et 3). La hausse de la turbidité a surtout été apparente en 1981 alors qu'une mesure a atteint 57 UTN; les valeurs moyennes sont cependant demeurées autour de 2 ou 3 UTN, ce qui dénote des eaux peu turbides. Le creusement des chenaux d'écoulement des eaux et une légère érosion des rives des lacs Boyd et Sakami maintiennent un niveau de turbidité de 1 UTN supérieur à ce qui avait été noté avant la dérivation.

La concentration de mercure dans l'eau n'a pas été détectable. Cependant, la hausse notée dans les poissons des lacs Boyd et Sakami indique que ce métal a été présent en plus grandes concentrations pendant les premières années d'opération du réservoir Opinaca et de la dérivation Eastmain-La Grande.

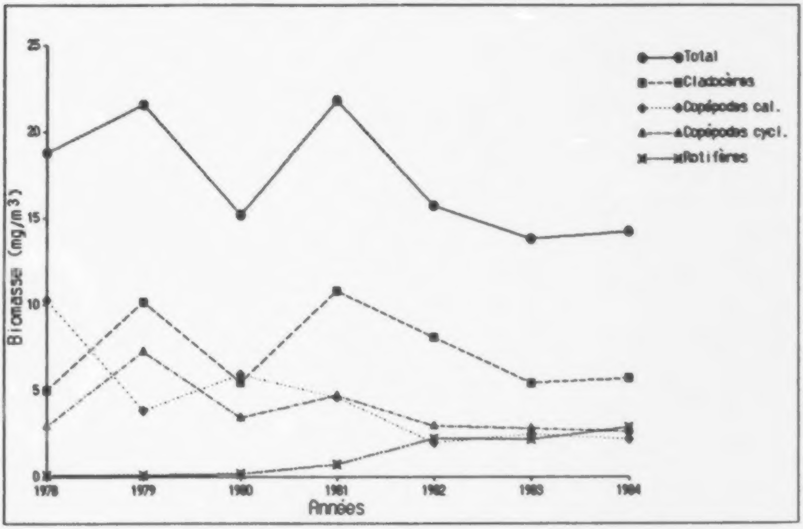

Figure 2. Abondance du zooplancton observée au sud du lac Sakami, avant (1979-1980) et après le début du détournement des eaux du bassin de la rivière Eastmain vers celui de La Grande Rivière.

La densité et la biomasse du zooplancton recueilli au lac Sakami ont été constantes d'une année à l'autre (Figure 2). Les seuls changements notables concernent une plus grande abondance des rotifères et des cladocères dans les échantillons au détriment des copépodes.

Les captures de poissons effectuées dans le cours de la dérivation ont présenté des structures de population différentes de celles précédemment observées au sud du lac Sakami. Cela serait dû à une réorganisation des associations de poissons en fonction des courants et aux apports provenant, par dévalaison, du lac Boyd et du réservoir Opinaca plutôt que par la disparition ou la prolifération de quelques espèces dans le lac Sakami (Figure 3).

Les données relatives aux répercussions de l'augmentation du débit et de la hausse du niveau des eaux, sur la faune terrestre ou les mammifères aquatiques ainsi que sur les formations végétales des rives, sont encore trop limitées pour pouvoir en tirer des conclusions probantes. Les observations futures nous apporteront probablement un meilleur éclairage. À date, la sauvagine et le castor semblent les éléments fauniques les plus susceptibles d'avoir été perturbés.

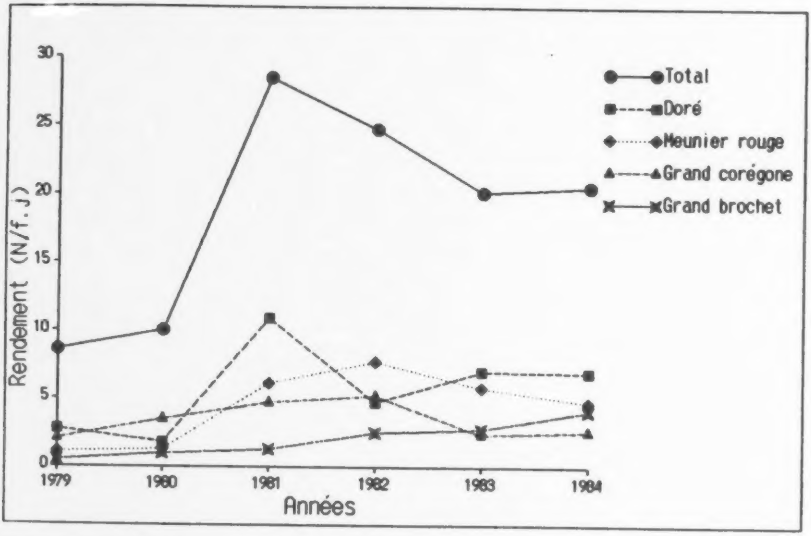

Figure 3. Évolution des rendements (N/f.j) des pêches effectuées au sud du lac Sakami, avant (1979-1980) et après le détournement des eaux du réservoir Opinaca vers celui de La Grande 2.

L'AVAL DU RÉSERVOIR DE LA GRANDE 2

Plusieurs événements sont venus perturber le régime hydrologique de La Grande Rivière depuis 1978 (Figure 4). Après un débit d'étiage hivernal, semblable à la moyenne des 20 dernières années, la rivière a enregistré en 1978 des crues printanières inférieures à la moyenne et un débit d'été exceptionnellement élevé causé par des fortes précipitations dans le bassin amont. La coupure de la rivière, complète au site du barrage de La Grande 2, a permis le remplissage rapide du réservoir du même nom mais n'a laissé, dans le cours inférieur, que les apports fournis par le bassin résiduel, soit environ 3% du débit original à l'embouchure (Roy, 1982). À mesure que les turbines étaient mises en service, la répartition des volumes d'eau relâchés s'inversait, les plus grands débits étant mesurés en automne et en hiver et les plus faibles, au printemps et en été.

Malgré les apports provenant de la rivière Eastmain depuis l'automne 1981, le module de La Grande Rivière n'a été réellement augmenté qu'après le remplissage des réservoirs de La Grande 3 (1981-1983), de La Grande 4 (1983) et Caniapiscau (1981-1984). Ce n'est qu'à partir de la fin de 1984 que les deux dérivations ont réellement permis de doubler le module de La Grande Rivière en le portant à 3 400 $m^3.s^{-1}$.

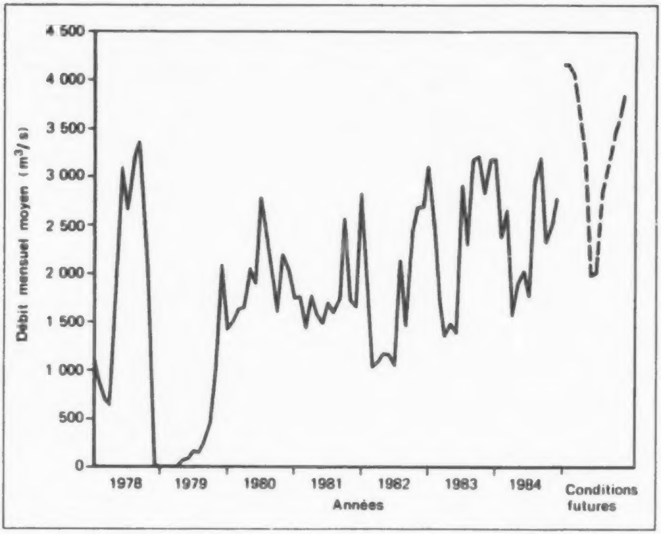

Figure 4. Hydrogramme de La Grande Rivière

En aval de La Grande 2, la rivière coule surtout dans des matériaux silto-argileux généralement recouverts par de minces placages de sable, des dépôts organiques ou des accumulations de matériaux organiques. Du km 117 au km 86, elle a érodé les matériaux fins ne laissant dans son lit que le roc, les blocs glaciaires et le gravier grossier. Entre les km 86 et 37, site du premier rapide important et de la future centrale de La Grande 1, la rivière est très encaissée et coule presque partout sur des argiles marines. Les vagues, les glaces et le courant maintiennent actifs de nombreux talus, particulièrement depuis le rehaussement du niveau causé par l'érection de batardeaux et le rétrécissement de la section d'écoulement au canal de dérivation temporaire du km 37 ainsi que par l'augmentation des débits et des vitesses de courant par les ajouts d'eau provenant des dérivations. En aval du km 37, les berges sont de plus en plus basses; malgré qu'elles soient sensiblement de même nature qu'en amont, elles manifestent plus de stabilité en raison d'un laminage des variations de débit enregistrées dans le secteur amont.

On estime qu'entre 300 000 et 500 000 m^3 de matériaux sont arrachés annuellement dans les deux derniers tronçons et transportés vers la baie James; cette quantité de sédiments en suspension ne réussit qu'à générer des turbidités de 1 à 5 UTN au centre de la rivière. Il peut arriver, comme le montre l'interprétation des photos aériennes, que des glissements se déclenchent soudainement (Lupien, Rosenberg, Journeaux et Ass., 1984). Il s'en est produit un récemment, le 5 septembre 1987, qui pourrait être classé parmi les glissements majeurs mais non parmi les plus grands de l'histoire millénaire de ce tronçon de rivière; le volume des matériaux transportés à la rivière est estimé à 4 000 000 m^3 dont les deux tiers ont dû se rendre à la baie James pendant les deux premières semaines. Cela donne un aperçu de la capacité de charriage de La Grande Rivière surtout depuis l'ajout des dérivations.

L'augmentation des débits et des vitesses de même que le soutirage de l'eau à des profondeurs de 20 à 40 m de profondeur dans le réservoir de La Grande 2 retardent la formation de glace sur une grande partie du parcours de la rivière en aval de ce réservoir. En été, les eaux turbinées prennent quelques semaines de plus pour atteindre leur température maximale qui ne dépasse plus maintenant 12°C, ce qui correspond à environ 5°C plus bas que les conditions antérieures (SEBJ et Laboratoire d'hydraulique La Salle Ltée, 1984).

Depuis le début des opérations de la centrale de La Grande 2, nous pouvons difficilement distinguer d'autres modifications concernant la qualité de l'eau, les valeurs mesurées étant toutes à l'intérieur des variations observées depuis 1973. La baisse du niveau d'oxygène dissous et la légère acidification causée par la décomposition de la matière organique, dans les réservoirs situés en amont, se sont vite estompées grâce à la turbulence causée par les rapides rencontrés entre les km 117 et 86 (Schetagne et Roy, 1985). Même des signes d'enrichissement des eaux des réservoirs ne sont pas perceptibles comme le montrent la chlorophylle α, le phosphore total et les formes d'azote et de carbone (Tableaux 1, 2 et 3).

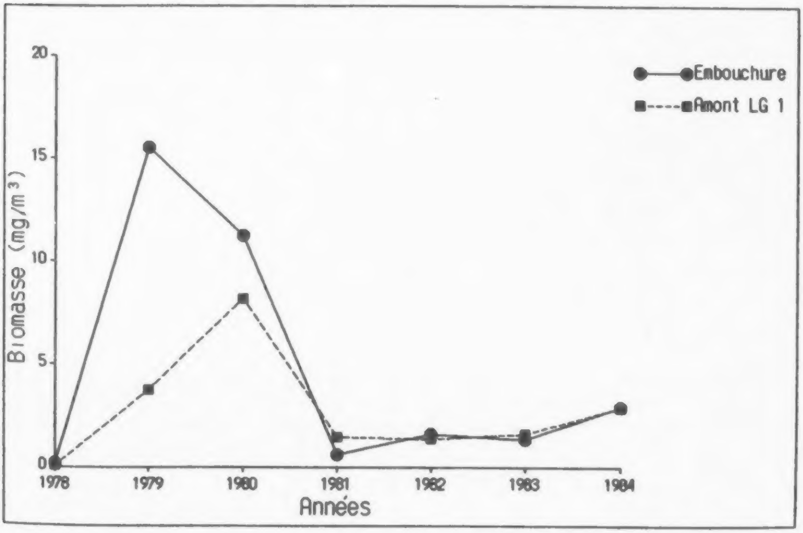

Figure 5. Évolution de la biomasse zooplanctonique dans La Grande Rivière avant (1978), pendant (1979) et après le remplissage du réservoir de La Grande 2.

Malgré la profondeur des prises d'eau à La Grande 2, les densités et les biomasses du zooplancton n'ont pas augmenté de beaucoup excepté pendant l'année de la coupure de la rivière et la première année d'opération en 1980 (Figure 5). Il semble, à l'examen des communautés rencontrées en amont et en aval de la centrale de La Grande 2, que beaucoup d'individus peuvent éviter la dévalaison car seulement 35% des organismes présents en amont se rencontrent en aval et, parmi ceux-ci, surtout de mauvais nageurs comme les rotifères, les larves de copépodes et des cladocères. Comme ce sont aussi de petits individus pour la plupart, seulement 10% de la masse par m^3 présente immédiatement en amont du barrage se rencontre en aval de la centrale (Roy, 1985).

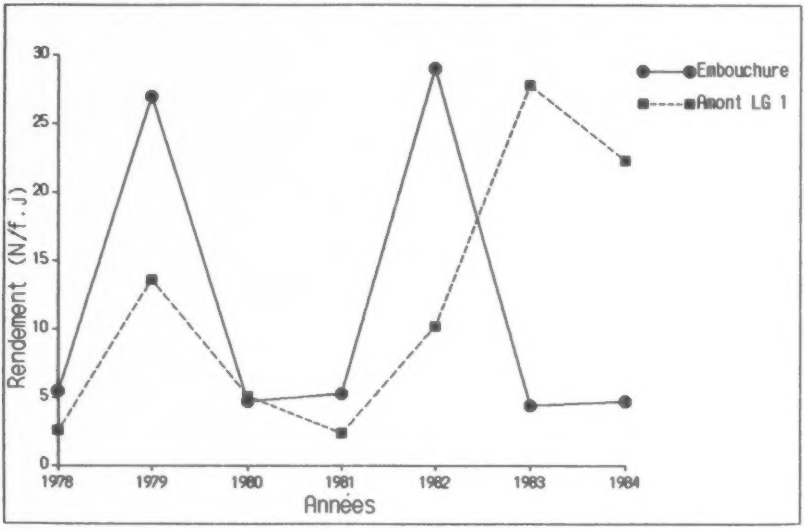

Figure 6. Rendements numériques (N/f.j) des pêches effectuées avant la coupure de débit (1978), pendant le remplissage du réservoir de La Grande 2 (1979) et après le retour des débits augmentés progressivement depuis 1983.

La figure 6 illustre les variations dans les pêches effectuées à l'embouchure de La Grande Rivière et à 1 km en amont du premier rapide considéré comme un obstacle à la montaison des poissons. La première hausse des rendements en aval eut lieu en 1979, année de la coupure de la rivière pour permettre le remplissage du réservoir de La Grande 2. Elle peut être expliquée par la concentration du volume des eaux saumâtres et une concentration des poissons qui, les autres années, occupent la zone d'épanchement des eaux douces dans la baie James. Les récoltes furent de nouveaux élevées en 1982. Les faibles débits estivaux de cette année sont encore responsables de la grande concentration des poissons près de l'embouchure de la rivière. L'espèce la plus communément capturée est le meunier rouge (Catostomus catostomus) avec une présence de 60% des prises d'une année à l'autre. Il faut noter toutefois que deux espèces communes, le grand corégone (Coregonus clupeaformis) et le cisco de lac (Coregonus artedii) quittent la rivière très tôt et n'y reviennent qu'en automne pour se reproduire ou pour hiverner. Lors du suivi effectué pendant l'hiver 1978-1979, il est ressorti que les ciscos de lac fournissaient 30% des captures au filet tandis que les meuniers rouges se limitaient alors à 20% des rendements (Roy, 1982).

En amont du premier rapide, il y eut aussi une concentration de poissons causée par une réduction du volume des eaux de la rivière. Cette observation a également été faite sur la rivière Eastmain après la coupure de débit (Messier et Roy, 1987). Les dévalaisons de poissons par les turbines et l'évacuateur de crues à La Grande 2 ont sûrement contribué par la suite à augmenter leur densité dans ce tronçon de rivière. Il peut aussi s'être produit un déplacement des poissons vers l'estuaire à mesure que les débits gonflaient; c'est dans les 10 ou 20 km en amont du site de La Grande 1 que les vitesses de courant sont les plus lentes. La même espèce qu'à l'embouchure, le meunier rouge, y est pratiquement toujours la plus abondante avec 57% du total des captures. Une tendance se manifeste présentement: la dominance de plus en plus évidente des espèces d'eaux froides comme le meunier rouge, le grand corégone, le cisco de lac et la lotte (Lota lota) aux dépens des espèces plus méridionales comme le doré (Stizostedion vitreum). L'omble de fontaine (Salvelinus fontinalis) et le touladi (Salvelinus namaycush) sont aussi plus fréquents depuis 1980 (Boucher et Roy, 1985).

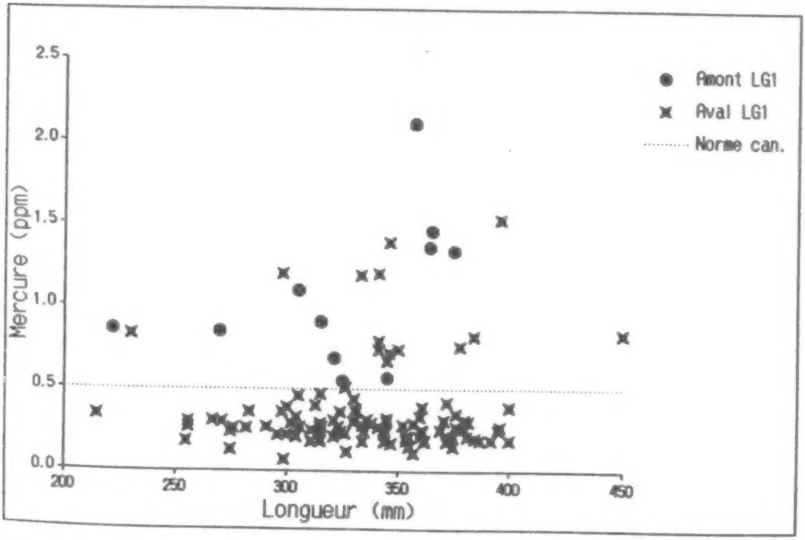

Figure 7. Concentration en mercure des ciscos de lac capturés en 1986 de part et d'autre du site de La Grande 1 (LG1).

Les chairs des poissons capturés en aval de La Grande 2 ont un contenu en mercure plus élevé qu'antérieurement. Ce phénomène a aussi été mis en évidence en aval du réservoir Opinaca et sur la rivière Churchill en aval du réservoir Smallwood, au Labrador (Messier et Roy, 1988). Les concentrations suivent un gradient négatif en fonction de la distance des centrales ou des ouvrages de contrôle. En aval du site de La Grande 1, il est possible de distinguer deux groupes de poissons: celui des résidents contenant de fortes concentrations en mercure et celui des migrateurs où les teneurs en mercure sont inférieures à cause de leur alimentation estivale dans la baie James (Figure 7). L'évolution de la contamination des poissons par le mercure dans la rivière devrait suivre de près celle observée dans le réservoir en amont à une exception près; certaines espèces dites non prédatrices comme le grand corégone pourraient continuer à consommer des jeunes poissons blessés lors de leur passage dans les ouvrages et ainsi maintenir des concentrations propres aux prédateurs.

CONCLUSION

L'addition des eaux de bassins adjacents peut modifier le milieu récepteur. Les dérivations des eaux du Complexe La Grande ont causé relativement peu de répercussions. Les détournements ont presque tous été effectués dans des régions de dépôts morainiques sauf en aval du réservoir de La Grande 2. Les eaux avaient, aux points de jonction, des compositions presque identiques car elles originaient des mêmes régions géographiques et avaient drainé des terres de même nature. Les mêmes organismes aquatiques se rencontraient dans tous les bassins sauf pour la ouananiche, une forme du saumon atlantique, qui était confiné à la rivière Caniapiscau. Sa dissémination dans La Grande Rivière est considérée comme souhaitable.

La plus grande instabilité des rives du tronçon inférieur de La Grande Rivière et la contamination de la chair des poissons par le mercure sont les deux principaux impacts identifiés à date. Il faut toutefois noter que le relâchement du mercure dans les réservoirs et sa propagation en aval se seraient produits sans les détournements; les sites de détournements seuls auraient été épargnés.

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SESSION B

INTERBASIN TRANSFER OF WATER:
PROCESS AND METHOD

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ENVIRONMENTAL IMPACT ASSESSMENT OF MAJOR CANADIAN WATER TRANSFER PROJECTS INVOLVING FEDERAL RESPONSIBILITIES

by Patrick J.B. Duffy[1]

ABSTRACT

Major projects involving interbasin transfer of water and involving federal government interests are subject to the federal policy on environmental assessment. The policy requires that the environmental implications of government actions be considered prior to taking irrevocable decisions and as early in the planning process as possible. The Environmental Assessment and Review Process is a self-assessment process whereby the initiating department is the decision-making authority ensuring that the environmental implications of all proposals are fully considered. Where adverse impacts are potentially significant or where there is significant public concern, the initiating department shall refer the proposal to the Minister of the Environment for public review by a Panel.

This paper outlines the federal policy and procedure and refers to several interbasin water transfer projects to illustrate potential impacts, mitigation measures, and technical review requirements and options, including joint federal-provincial reviews, where there are shared responsibilities and interests.

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POLICY

The federal government policy on environmental assessment requires that the environmental implications of government actions be considered prior to taking irrevocable decisions and as early in the planning process as possible. The EARP is a self-assessment process; the initiating departments department is the decision-making authority and ensures that the environmental implications of all proposals are fully considered. Where adverse implications are potentially significant, or where there is significant public concern the initiating department shall refer the proposal to the Minister of the Environment for public review by a Panel.

The implications shall include the potential environmental effects on and from the project and directly-related social effects as well as effects that are external to Canadian territory. The consideration of the proposal will include the concerns of the public regarding its potential environmental and related social effects. In the case of proposals referred for a public review by a Panel, with the approval of the Minister of the Environment and the Minister of the initiating department, consideration of a proposal may also include such matters as the general socio-economic effects, technology assessment, and the need for the proposal.

Where a proposal is subject to environmental regulation independent of the Process, duplication of public reviews is to be avoided. The initiating department shall use a public review by a Panel under the Process as a planning tool at the earliest stage of development of the proposal. The results of the public review should be made available for use in any subsequent regulatory deliberations respecting the proposal.

OPERATING PRINCIPLES

The purpose of the Process is to implement the federal government's policy on environmental assessment. Implicit in this is the requirement that the Process should be used as a planning tool, and therefore it is most effective if applied at the early stages of project planning. Early application improves the effectiveness of both initial assessments and public reviews. It is also important that decisions taken during initial assessment be accessible to the public.

The Process operates on the principle that the initiating department shall ensure that each proposal, for which it is the decision making authority, is subjected to an initial assessment. The initial assessment is to determine whether, and the extent to which, there may be any potentially adverse environmental effects from the proposal. Responsibility for decision-making under the Process belongs with the initiating department and cannot be delegated to another agency or jurisdiction, although relevant advice and information may be obtained from other sources.

Another operating principle is that information on the proposal should be made available to the public to allow the public to comment on its potential environmental effects. While there may be instances where this is not practical, public involvement is often important to project planning and should therefore commence early in the planning work.

APPLICATION

The Process applies to any proposal:

(1) to be undertaken directly by an initiating department, for example, an extension of an existing airport runway by Transport Canada;

(2) that may have an environmental effect on an area of federal responsibility, for example, a hydroelectric power generation project with potential to flood national park lands;

(3) for which the Government of Canada makes a financial commitment, for example in railway relocation projects in some urban centres partially funded by Transport Canada;

(4) that is located on lands, including the offshore, that are administered by the Government of Canada, such as the National Parks.

Where the decision-making authority for a proposal is a corporation listed in Schedule C of the Financial Administration Act, the corporation is expected to develop a corporate policy which would require the routine application of the Process unless the application of the Process is beyond the legislative mandate of the corporation.

The EARP Guidelines Order (1984), stipulates that federal boards or agencies exercising a regulatory function are obliged to apply the Process if:

(1) there is no legal impediment to doing so; and

(2) procedural duplication does not result.

A legal impediment could occur, for example, if a board or agency had no legal authority to include environmental factors in its decisions. For instance, an agency set up to regulate aircraft safety could not use that federal decision-making role to apply EARP to aircraft owners and force environmental assessments not related to aircraft safety.

For projects requiring public review under EARP as well as under a regulatory process, there is an obvious need to avoid potentially costly duplication. An example is the National Energy Board (NEB) which incorporates environmental matters into its decision-making process. In such cases, if the EARP was used at an early stage, it could serve as an early planning tool for the project proponent by making the major environmental recommendations which could be considered subsequently in the NEB's detailed regulatory review.

Some other federal regulatory agencies, for example the Atomic Energy Control Board (AECB), may choose to apply the EARP to their decisions to assist them in incorporating environmental factors. In most cases, it is not practical for regulatory agencies to use the Process as an early planning tool since they are not involved with the proposal until the proponent makes an application. Nevertheless, if it becomes known that such a board will be applying EARP principles routinely to its decision-making, it is expected that proponents will plan for such examination and in effect use EARP principles in their early planning.

The Process requires that a proposal be reviewed for its environmental effects and those social effects which are directly related to the environmental effects. For example, a series of water control or hydro dams might result in flooding (environmental effects) leading to disruption of hunting and trapping activities and seasonal harvests (social effects). As noted above the subject matter under review may be broadened to include such items as general socio-economic effects of the proposal, technology assessment, and the need for the project, but only with the mutual agreement of the Ministers of the Environment and the initiating department.

The Process applies to Canadian project proposals which affect the environment external to Canadian territory. For instance, offshore oil and gas exploration may have the potential to adversely affect nearby coastlines and waters in the U.S.A., Denmark (Greenland) and France (St. Pierre and Miquelon). Where there is the possibility of international transboundary effects initiating departments that consider such projects must consult with the Department of External Affairs at the earliest possible stage of a project so that complicated and costly delays at a later stage can be avoided.

ADMINISTRATION OF THE PROCESS

FEARO is responsible directly to the Minister of the Environment for the administration of the process. FEARO receives policy direction from the Minister of the Environment but it operates independently of the Department of the Environment, and is linked to that department for logistical administrative purposes only.

DESCRIPTION OF THE PROCESS

The purpose of this section is to give a general overview of how the Process works.

Throughout the Process, it is important to keep environmental, social, economic and technical feasibility studies related to each other and conducted to about the same level of detail. If this does not happen, decisions will be made without the benefit of adequate information in one of the areas. Environmental studies cannot and should not be separated from other studies being carried out.

The initial assessment undertaken by an initiating department has two possible stages:

(1) screening and, if necessary,

(2) further investigation to study unknowns resulting in a report called an Initial Environmental Evaluation.

Experience shows that a great majority of the projects generally meet environmental criteria and are approved as a result of screening. Only a small fraction of the projects require further investigation and even fewer are referred for public review by a Panel.

Generally speaking, for every 1,000 projects which are screened, 100 move ahead to further study, and 1 project may go to public review. A variety of projects and activities which have been recently assessed and which cover a range of impacts are illustrated in the photographs which follow.

The main steps of the Process are described in the following text and in a schematic diagram in Figure 16 (See fold out diagram, last page).

Step 1

The Process commences when a proposal for a project, program or activity is identified in an initiating department's work program. The proposal should be sufficiently developed to identify an initial list of environmental issues, the alternatives and to identify most of the affected parties. If environmental considerations are properly integrated into the planning process, very few projects will be delayed for environmental reasons. This is to illustrate that environmental assessment is not separate from other project planning activities.

Step 2

Screening is a systematic, documented assessment of environmental implications of a proposal, including the significance of adverse environmental consequences. Proper note should be made of environmental factors which may impact on the project. This is particularly important where these factors cause conditions requiring special operating or construction procedures, as related, for example, to human safety and working conditions. Screening determines the need to mitigate environmental impacts or to carry out modifications to the project plan to reduce impacts or whether further investigation is required. At this step, if there are possible international transboundary effects, then, as noted above, the Department of External Affairs must be consulted. FEARO should be advised as well.

Experience shows that many initiating departments carry out screening with the project manager using the Guide to Environmental Screening (FEARO, 1978) and obtaining technical advice from departments such as Environment Canada, and Fisheries and Oceans Canada.

Screening results in one of nine outcomes:

(1) Automatic exclusion, based on lists defined on a program-by-program basis. The project proceeds.

(2) No adverse effect. The project proceeds.

(3) Effects can be mitigated with known technology, environmental design, and conformance to legislation and regulations. The project proceeds with mitigation and monitoring measures identified and recorded.

(4) Potentially adverse effects are unknown. The proposal is given further study until a decision can be made.

(5) Ability to mitigate effects is unknown. The proposal is given further study until a decision can be made.

(6) Where potentially adverse effects are significant, according to criteria developed by FEARO and the initiating department, then the proposal shall be referred to the Minister of the Environment for a public review by a Panel.

(7) Where there is public concern about potential environmental effects, such that a public review is desirable, then the proposal shall be referred to the Minister of the Environment for a public review by a Panel (see Section 13, Order in Council).

(8) Automatic referral based on lists defined on a program-by-program basis. The project is referred for public review by a Panel.

(9) Potential adverse environmental effects are unacceptable, in which the proposal must be modified and then re-screened, or be abandoned.

Step 3

Further investigation is the next step for proposals which have passed the screening stage and have not been referred for public review by a Panel or approved for implementation but require additional study. This step entails a documented assessment of the potential environmental impacts of a proposal, and it requires that further study be done to provide information on the nature, extent, and significance of impacts, and the efficacy of known mitigation measures. The work is usually documented in an Initial Environmental Evaluation (IEE) (see Section 3.8). Experience has shown that, at this stage, procedures by initiating departments vary considerably, some involving additional field research and surveys, and others involving reviews of alternative designs. Procedures are sometimes very dependent on the nature of the project. It is also customary at this stage to seek the advice of departments with special expertise. Depending on the complexity of the issues involved, the study approach can vary from a scoping meeting to find out the need for more definite information, to the undertaking of a prescribed study and the production of a report. Documentation of results in the IEE also varies widely, from short reports to volumes of 100 pages or more. The size and format will continue to be left to the judgement of initiating departments. The main objective remains unchanged however; that is, to establish the significance of potentially adverse environmental effects, to identify useful mitigative measures from existing technology, and to report these results and the related decision on the project in a clear concise manner suitable for public scrutiny.

Since 1976, the term Initial Environmental Evaluation (IEE) has been used to describe this documentation of results of further investigation.*

Further investigation will result in one of three documented decisions being taken:

(a) Effects are understood and can be mitigated; the project therefore may proceed with prescribed mitigation and monitoring measures.

(b) Effects and/or public concern are significant and a public review by a Panel is therefore warranted, in which case the proposal is referred to the Minister of the Environment for such a review (Section 13, Order in Council).

(c) Effects are significant and unacceptable, in which case the proposal must either be modified and subsequently re-screened or be abandoned.

These initial assessment decisions will be published regularly in a bulletin issued by FEARO and this will cover decisions made at the screening stage or after additional investigations have been completed. The record will consist of information on proposals forwarded by initiating departments. In this way, both government and non-government agencies and other interested parties can be assured that the Process is being implemented.

Step 4

The next step in the Process for proposals warranting such action is referral of the proposal by the Minister of the initiating department to the Minister of the Environment for review by a Panel. The Panel is normally chaired by the Executive Chairman of FEARO or his delegate and is appointed by The Minister of the Environment who issues the Panel with terms of reference after consultation with the Minister of the initiating department.

Step 5

The environmental assessment documents are prepared. Depending upon the nature of the review these may include guidelines prepared by the Panel, for the preparation of an environmental impact statement (EIS) to be prepared by the project proponent or, in some cases, the initiating department. Panels usually seek public comment on EIS guidelines before they are finalized.

Step 6

Once the environmental assessment documents are completed, the public review of the EIS is carried out. If deficiencies are identified, then the proponent is asked to address them in writing before public hearings are held. Then the Panel holds public hearings on the EIS.

Step 7

The Panel prepares a report on the review for the Ministers of the Environment and the initiating department. The report is usually a description of the impacts of the proposal with recommendations on how to address these impacts.

Step 8

The two Ministers then make the Panel report public.

Step 9

The Minister for the initiating department will determine the manner in which the decisions taken will be made public (Section 33(e), Order in Council) (Duffy, 1986).

Canadian experience with interbasin projects has been usefully described by Quinn (1987) and Rosenberg et al (1987) among others. Quinn has summarized the highlights as follows:

> Several findings are apparent from a review of Canadian water diversion trends. First, most diversions utilize short cuts and natural channels to advantage in reordering the dense and disorganized drainage of a heavily glaciated landscape. Second, interbasin diversions are numerous, some are long-established and those most recent are massive in scale, raising diversion totals to a magnitude unknown in any other country. Third, they are scattered widely across the country, most of them remote from more populated regions. Fourth, hydro is the dominant use; most projects have been developed by provincial corporations whose principal objective has been to maximize low-cost power generation and thus to move electric power, not water, to southern markets. Fifth, little attention was given to social or environmental conditions by project developers before the mid 1970s, when native peoples directly affected and environmental organizations began to insist on a better deal; planners still have a lot to learn about projecting future needs and implications. Sixth, the existing pattern of interbasin diversions in Canada is unlikely to change significantly in the next few years, partly because of surplus hydro capacity and the potential for more hydro without more diversions and partly because rising prices for water should encourage conservation and greater efficiency by users.

Full predictive environmental assessments of major projects involving water diversion are few in number but there have been a number of retrospective assessments of completed projects. Projects in the former category include the Wreck Cove Hydro Project, Nova Scotia and the Cat Arm Hydro Project, Newfoundland. An example for the second category is the Churchill - Nelson Hydro Scheme in Manitoba.

Several water diversion projects have been the subject of environmental assessments and subsequently been shelved. Examples are the McGregor Diversion and the Kootenay Diversion of B.C. Hydro and the Garrison Project of North Dakota.

There are a number of explicit federal responsibilities which permit the government to initiate or participate in the environmental of such projects. These include the *Navigable Waters Act*, *Fisheries Act* and the *Boundary Waters Treaty* of 1910 as well as the *National Parks Act*, and other legislative instruments. Provision is also made in the Order in Council on the Federal Environmental Assessment Review Process to allow federal-provincial co-operation in environmental assessment. Such co-operation has been somewhat more formalized in an agreement between the Government of Alberta and the Federal Government (FEARO, 1986).

DUFFY, P.J.B. (Ed.). 1986. Initial assessment guide: Federal Environmental Assessment Review Office. pp. 36.

F.E.A.R.O. 1986. Agreement concerning environmental impact assessments of projects in Alberta with implications for Canada and Alberta. Federal Environmental Assessment Review Office, Ottawa. pp. 3.

QUINN, F. 1987. Interbasin diversions and their implications. J. Soil and Water Conservation. pp. 6. Under review.

ROSENBERG, D.M., R.A. BODALY, R.E. HECKY, and R.W. NEWBURY. The environmental assessment of hydroelectric impoundments and diversions in Canada. pp. 71-105. IN: M.C. Healey and R.R. Wallace (Eds.) Canadian Aquatic Resources. Canadian Bulleting of Fisheries and Aquatic Sciences 215 p. Ottawa.

THE ECONOMICS OF INTERBASIN WATER TRANSFERS:

SELECTED METHODOLOGICAL ISSUES

G.C. Van Kooten, S.N. Kulshreshtha and C. Holmes[1]

ABSTRACT

In this paper, selected issues regarding the economics of interbasin water transfers are examined. Some current and proposed interbasin transfer projects are reviewed and methods for evaluating the economic efficiency of such transfers are discussed. In particular, the cost-benefit methodology needs to be modified as the assumption of smallness is violated. Therefore, it is recommended that applied general equilibrium modeling be used in conjunction with cost-benefit analysis to evaluate economic efficiency. Applied general equilibrium models are also an appropriate tool for determining regional income redistributions resulting from large-scale water transfer projects. Finally, environmental concerns are addressed and suggestions for evaluating these nonmarket values in a cost-benefit framework are provided.

KEY WORDS: interbasin water transfer, cost-benefit analysis, applied general equilibrium models, environmental economics, nonmarket values

INTRODUCTION

Rising population coupled with per capita economic growth has increased the demand for fresh water in North America, particularly in

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the more arid regions of the continent. Since water resources are not evenly distributed, one way to satisfy growing water demand in the more arid regions is to transfer water from areas where there is a surplus (Peet and Day 1980). Water transfers have also be implemented to deflect watercourses away from worksites or communities, to create concentrated bodies of water for more efficient energy development, and to improve the carrying capacity of an existing water course (Quinn 1981). However, the focus of this paper is on an economic evaluation of rather large interbasin water transfers. Within this evaluation framework, the focus is concentrated on the issue of economic efficiency, with particular emphasis upon the following: (i) to look at an appropriate methodology for examining economic efficiency and (ii) to discuss a methodology for including in this evaluation a major component of economic efficiency, namely, the preservation, wetlands, recreational and environmental values of water.

Need for Interbasin Water Transfers in Canada

From the onset, it should be noted that there are some questions regarding the need for interbasin water transfers of the size and nature described in the report of the Inquiry on Federal Water Policy (1985, p. 127).[2] An alternative to wholesale transfers of water is complete specification of property (water) rights along with proper management of water supplies, especially in the more populated, high-growth areas. On the Canadian prairies, for example, one reason for existing supply problems is a result of the right to consume water freely, while the goal of water management is to increase the supply of water rather than to question its distribution. The Canada Water Resources Act of 1970 gave water rights in the form of licenses to anyone who made an application. To obtain a license, the users simply had to stipulate the amount of water they proposed to consume, which was usually more than they needed (Percy 1981). Water rights have been distributed in this way until the available supply of water in the basin is fully allocated.

An institutional framework for appropriating water rights in western Canada has also evolved. The Prairie Provinces Water Board was created in 1948. The Board lasted until 1969 when it was reconstituted under an apportionment agreement between the governments of Canada and the three prairie provinces. The new agreement assured Manitoba of at least one-half of all the water flowing eastward from Alberta into Saskatchewan and one-half of total natural flow of streams and tributaries in Saskatchewan. Similar apportionment agreements have also been made between Canada and the U.S.. These agreeemtns ignore any economic or environmental consequences of such decisions. The 1970 Water Resources Act enabled the federal government to become involved in water management in the provinces, and, in 1971, Environment Canada was formed to enforce resource management. Despite these attempts to manage the nation's fresh water, problems with enforcement and conflicts over water resource use remain.

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[2] These questions and related issues are discussed in the next section of this paper.

Nevertheless, it is true that water can be a constraint on the economic growth of a region when economic activities are inhibited by a water shortage.[3] According to Burke (1980), the river basins in Canada that will be subject to the most demand pressure will be those feeding the South Saskatchewan River in Alberta and Saskatchewan. Population growth, industrial growth, agriculture, and other resource development in southern Alberta and Saskatchewan will place new demands in this water-deficient region of 414,000 square miles which stretches across the prairie provinces and even into the northern United States. A series of studies conducted by the Saskatchewan-Nelson Basin Board (SNBB) examined the potential for diversion schemes so that additional water could be provided in this area. The studies, completed between 1967 and 1972, examined topics such as location of possible reservoirs, estimates of the natural supply of water at various points, water use, and possible increase in water supplies through further development schemes. The studies also included possible diversion effects on major river regimes, water quality, the biological impacts, recreation, wildlife and donor basins (SNBB 1972). The conclusion of the study was that large supplies of water could be made available throughout the basin, but at an uncertain cost to the environment. However, the study fails to examine current water uses and water markets, and also ignores economic consequences of any interbasin water transfer.

Experience in U.S.

In the United States, water shortage has been a part of the southwest for many years. In the Salt River valley of central Arizona, for example, in some places the ground has already settled several hundred feet due to pumping of water from under the valley. Citizens of the southwest consider water necessary for growth as the region is the fastest growing area in the United States (Bocking 1972). In general, Canadians accept the idea of providing water to the United States, but they do not question how the water is currently being used and if there is any waste. It is apparent that there is no immediate crisis if current water use is taken into account. Bocking points out that 20 to 30 percent of available water is lost through leakage of water mains in most U.S. cities.[4] This is primarily because water is cheap and there are no incentives to conserve.

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[3] Interdependence between regional growth and water resource investment has been a subject of inquiry by Howe (1968), Cox, Gover and Siskin (1971) and Garrison (1971). As noted by Lewis et al. (1973), the empirical evidence for a relationship is mixed. There is some evidence of a positive relationship between water development and employment growth, particularly in water intrinsic industries. Using a six nation study, Loveless (1985) found a high correlation between water resource development and aggregate socioeconomic indicators.

In the southwestern United States, 90 percent of the water is used for agriculture (Howe and Easter 1971). Much of this water is used for the irrigation of cotton—a crop usually in surplus and which is subsidized by the government—or for irrigation of low value crops such as barley and alfalfa. In addition, irrigation in the U.S. is subsidized; however, this has reduced costs of production for some irrigated crops relative to their production by dryland techniques, thereby pushing out of production land that could normally grow these crops without irrigation. Howe and Easter (1971) estimate that 5 to 17 million acres of land were taken out of production between 1944 and 1964 as a direct result of subsidized irrigation. This resulted in social costs and increased urban ghettos as unemployed farmers moved to the cities.

While Howe and Easter's discussion raises questions about need for interbasin water transfers, it appears that continued and expanding reliance on irrigated agriculture results in a greater demand for water. This is exacerbated by possible reductions in the availability of underground water. Under these conditions, interbasin water transfers appear to be an engineering solution to actual or perceived future water shortages.

Objectives and Organization of the Paper

The procedures for evaluating large interbasin water transfers from the point of view of allocative efficiency are examined in this paper. The issues of current misallocation of water, either through transfers or existing sources, while important, are not discussed. In the next section, a brief overview of some of the projects which have been proposed over the last three decades for transferring water from water surplus to water deficit regions in North America is provided. Then, in the third section, the methodology for evaluating such investments in water development projects is investigated. Water has value (i) in agriculture, (ii) in municipal and industrial uses, and (iii) as wetlands for wildlife habitat, recreation, preservation and so on. This latter demand for water is examined in detail in section 4 because it is often overlooked as something to be described qualitatively, although, given the uncertainty of environmental impacts and the importance of preservation value (Crocker 1985), an attempt should be made to place an economic value on such demand. This issue is also discussed.

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[4] In New York alone, 300 million gallons is lost daily through water main leakages, while another 8 million gallons is wasted daily in other ways.

OVERVIEW OF MAJOR WATER DIVERSION PROJECTS IN NORTH AMERICA

Concern over water shortages in the 1960s spurred the Ralph M. Parsons Company of Los Angeles to draw up a proposal called the North American Water and Power Alliance (NAWAPA). This project is designed to bring 110 million acre-feet of water that would otherwise flow into northern seas to water-deficit regions in the south (Bocking 1972). NAWAPA would include six dams over 1,500 feet in height, a huge reservoir formed in the Rocky Mountain Trench of British Columbia, a shipping canal across the prairies from the Great Lakes, and numerous other dams, lakes, canals and reservoirs. The Columbia River-Colorado River portion of this project would transfer 2.4 million acre-feet per year with capital costs of $1.4 billion. The capital cost of the total project over a twenty-year construction period was estimated at $100 billion, which is $280 to $355 billion in 1984 dollars, including $16.6 billion for land acquisition and community relocation. However, these figures only account for the cost of building the project and ignore the social and environmental costs (Day 1985). While it is unlikely that this project will ever be developed, water transfers on a smaller scale might proceed if political and economic conflicts can be overcome.

Another proposal by Lewis Gordy Smith is called the Western States Augmentation Concept and involves reversing the flow of the Liard River and part of the MacKenzie River (Brocking 1972). The water would then be pushed up the Rocky Mountain Trench through the Williston reservoir, transferred to the Fraser and diverted south to the United States.

Roy E. Tinney developed the Central North American Water Project (CeNAWP), which would cost approximately one-third that of the NAWAPA project (Pearse, Bertrand and MacLaren 1985). It involves taking water from the MacKenzie, Churchill and Nelson Rivers flowing into Great Bear Lake through Great Slave Lake and Lake Athabasca into Lake Winnipeg. From there it would be diverted southward into the United States and east to Lake Superior. Tinner did not intend anyone to take this proposal seriously, but only wanted to show that, for a water diversion the size of NAWAPA, a less expensive and more efficient method could be developed.

Edward Kuiper also considered possible water diversions in Canada, but he looked ahead to predict the future needs and uses of water when making his estimates. The annual flow of the Nelson, Churchill, MacKenzie and Yukon Rivers is approximately 313 million acre-feet. Kuiper felt it would be reasonable to divert 230 million acre-feet, with 100 million acre-feet sold to the U.S. (Bocking 1972).

In 1959, Thomas Kierans proposed the Great Recycling and Northern Development (GRAND) Canal, which would turn James Bay into a fresh water reservoir. The water would then be pumped south through canals and the Ottawa River into the Great Lakes. The estimated cost of construction for this project is $100 billion in 1984 dollars (Day 1985).

Examples in Howe and Easter (1971) of interbasin transfers already in operation give an idea of the potential costs of such projects. The diversions from the Delaware River Basin average less than 1 million acre-feet per year, but by the mid-1960s, the city of New York had already invested more than $500 million over a thirty year period. The Colorado-Big Thompson diversion carries 230,000 acre-feet of water, but the total investment was $161.6 million. In an *ex post* study, Howe et al. (1982) estimate that the project yielded a national benefit-cost ratio of 1.16, but a regional B-C ratio of 23.05![5]

There are numerous projects in Canada that have been completed or are under study: Kettle Rapids in Manitoba, the Mica Creek dam in British Columbia, the Yukon-Taia project in the Yukon and British Columbia, the Bennett dam on the Peace River, the Columbia Treaty dams in British Columbia and Montana, the Moron Dam on the Fraser River, the Saskatchewan-Nelson Basin Studies, the Gardiner Dam on the South Saskatchewan River, and the Churchill-Nelson Hydro development in Manitoba (Bocking 1972). All of these projects involve some diversion of water and they all have an impact on the national, and particularly the regional, economies. However, there remains a question as to whether the projects are economically efficient from a social point of view.[6] The issue of social economic efficiency is the focus of the remainder of this paper.

MEASURING THE ECONOMIC EFFICIENCY OF INTERBASIN WATER TRANSFERS

In order to determine whether a resource development project such as a large-scale interbasin water transfer project should be built, it is useful to investigate the economic efficiency benefits of such a project. This will enable the authority to make a better decision regarding the allocation of funds for such a development. Hartman and Seastone (1965), Beattie et al. (1971), Howe and Easter (1971), Keith, Anderson and Clyde (1973), Howe et al (1982), and Vaux and Howitt (1984) have examined the economic efficiency and income transfer effects of interbasin water transfers. While both the economic efficiency benefits and the regional or income transfer benefits attributable to the water development project have been presented, there does appear to be some confusion in some of the studies regarding what constitutes an economic benefit and what constitutes an income transfer. Some of the studies include the secondary benefits along with direct benefits (Howe et al. 1982); others separate them recognizing that direct benefits generally refer to economic efficiency while secondary benefits, or rather impacts, refer to income transfers (Beattie et al. 1971). Stabler, Van Kooten and Meyer (1987) provide a distinction between these concepts as they are employed in project evaluation.

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[5] As argued by Stabler, Van Kooten and Meyer (1987), the practice of including regional benefits in the computation of a national B-C ratio is inappropriate for considering whether this project was worthwhile from an economic efficiency point of view. However, this does not imply that regional development is not a valid criterion for assessing such transfers.

[6] There is also the issue of whether or not a greater economic impact on the local economies could have accrued if the monies which have been or are about to be spent on these projects were spent in some other way in the project-region. On this issue see Stabler, Van Kooten and Meyer (1987).

Since the mechanics of cost-benefit (C-B) analysis are discussed elsewhere (e.g., U.S. Water Resources Council 1979), the focus of this section will be on that methodology which is unique to large interbasin water transfers as opposed to (small) water projects such as the construction of a single dam for purposes of generating electricity and providing water for irrigation. Following Beattie et al. (1971), it is possible to identify economic conditions for making water transfers. The objective to be maximized is stated as follows:

$$\text{maximize } \Pi = \sum_{t=0}^{n} (B_t - C_t)/(1+r)^t, \qquad (1)$$

where Π is the social value of incremental goods and services resulting from the project—that is, net present value of social welfare;

B_t represents all of the project's social benefits (some of which may be negative) accruing at time t,

C_t represents the project's social costs at time t;
r is the social rate of discount; and
t is generally incremented annually, where 0 refers to the current (starting) time period.

Equation (1) can also be written as:

$$\Pi = (TVP_M - TFC_M) - [C_T + (TVP_X - TFC_X)], \qquad (2)$$

where TVP denotes total present value of goods and services, TFC denotes total present value of factor costs, C_T refers to the present value of all project costs, and M and X refer to the region of destination (importing region) and origin (exporting region), respectively. This means that TVP_M refers to the present value of all goods and services foregone in the region of origin as a result of the project, while TFC_M refers to the factor costs of producing those goods and services which are subsequently foregone. The latter are a saving due to the project. Likewise, TVP_X is to be interpreted as a benefit from the project, while TFC_X is a cost.

Two necessary conditions must be met if a project is to be efficient from an economic point of view.

$$\text{(i)} \quad C_T + (TVP_X - TFC_X) \le C_A, \qquad (3)$$

where C_A denotes the present value of costs of the least costly alternative to the water transfer scheme which meets the same objectives and the other variables are defined as previously. This condition states that the transfer scheme must be less costly than some alternative scheme or any other project which achieves the same goal.

$$\text{(ii)}\quad VMP_X = MC_T + (VMP_M - MFC_X), \qquad (4)$$

where VMP refers to the value of the marginal product, MC_T denotes the marginal cost of transferring water from one region to the other, and MFC_M is the marginal factor cost incurred in the region of destination. This condition states that water must be transferred from one region to the other until the marginal social benefits of doing so are equal to the marginal social costs. In practice, since transfers of water are likely to be "lumpy", it is sufficient to satisfy the following:

$$\text{(ii')}\quad VMP_X \geq MC_T + (VMP_M - MFC_X). \qquad (5)$$

Notice that, in this discussion, nothing has been said about secondary impacts or "benefits". The reason is that secondary benefits are pecuniary in nature and amount to a transfer of income from one region or sector of the economy to another. This does not, however, imply that secondary benefits are not real, particularly where water transfers from Canada to the U.S. are concerned. If the designation region is paying for the water development project, then secondary benefits become important, as Stabler, Van Kooten and Meyer (1987) point out. However, this will not generally be the case if the transfer occurs within the same country or same level of government.

The foregoing methodology is the one most familiar to cost-benefit analysts. However, it only holds as an approximation for small water projects which have no effect on prices, income distribution and so on. It is not appropriate to use in the evaluation of large projects such as interbasin water transfers of the magnitude described in the previous section. Rather, one alternative to C-B analysis is applied general equilibrium (GE) modeling. Applied GE models "provide an ideal framework for appraising the effects of policy changes on resource allocation and for assessing who gains and who loses" (Shoven and Whalley 1984, p.1008). They are probably a better tool than input-output analysis for evaluating the income redistributional and welfare impacts of a resource development project. Indeed, Diewert (1983) recommends that they be used in cost-benefit analysis.

Applied GE models are constructed from economic theory. Functional forms for the utility functions of each consumer and the production functions for each commodity are specified.[7] Utility maximization and cost minimization subject to the usual constraints determine the supply functions and the demand functions for both outputs and inputs. An initial endowment of inputs is assumed, the supplies and demands are set equal to each other, and an assumption is made about profits (generally zero profits). Using data from a single year or an average of several years, the parameters of the model are obtained through deterministic calibration as opposed to stochastic estimation.[8]

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[7] Models tend to have a small number of representative consumers (e.g., rich and poor) and several commodities (e.g., manufactures and agricultural commodities). The structure of the model will depend upon the particular application. In a regional trade model and in a model to evaluate interbasin water transfers, there may be a single consumer for each region in the economy with several outputs produced in each region. However, the endowments in each region differ, especially water endowments.

The advantages of applied GE models for project evaluation are twofold. (1) General equilibrium models focus on "the welfare impacts of policy changes, with particular emphasis on aggregate efficiency impacts. Although distributional effects may be considered, the bottom line in most policy evaluations is whether any given policy change raises or reduces aggregate welfare" (Shoven and Whalley 1984, p.1022). That is, the applied GE models can be used to provide a detailed evaluation of who gains, who loses and by how much as a result of a water development project or a policy change. (2) The measure of welfare employed in the GE methodology is the correct one from an economic-theoretic point of view. Assuming that there are no externalities (see next section) or that these are appropriately accounted for, an applied GE model can be used to determine the Hicksian compensating variation or equivalent variation (Boadway and Bruce 1984) of a government policy or project development as illustrated by Shoven and Whalley (1984, pp. 1013-14).

Finally, there is one other aspect of large resource development projects, such as interbasin water transfers, which rules out anything but a general equilibrium methodology. Interbasin water transfers are frequently so large that they have an impact on prices in the economy. For example, if water is transferred from one region to another, trade theory suggests that the price of water will increase in the region of origin and decrease in the region of destination.[9] Hence, the change in the price of water is sufficient to rule out, or at least impose added difficulties on, the traditional methodology. What is required is the construction of shadow prices for each of the goods in the economy. A GE model generates new prices automatically as a part of the "counterfactual" solution, which is then compared to the original or pre-project solution. There is no need to construct shadow prices or assume that prices do not change. The problem with traditional C-B analysis is that quite large errors in the welfare measures may result, which is not the case when applied GE modeling is used.

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[8] An example of how to construct such a model and use it for policy analysis can be found in Shoven and Whalley (1984).

[9] The authors recognize that, in much of Canada, water is not priced.

INCLUDING NONMARKET VALUES: ENVIRONMENT EFFECTS

There is one aspect of cost-benefit analysis that is often neglected in project evaluations because it is difficult to analyze and measure, namely, externalities. External or third-party effects are the nonmarket values attached to water use; they occur when the actions of individuals or groups of individuals have economic consequences which are not priced by the market (Hartman and Seastone 1970).[10] For interbasin water transfers, the nonmarket demands for preservation, recreation and wetlands are important and must be taken into account in any evaluation of interbasin water transfers. In this section, we examine the problem associated with nonmarket demand for water by first considering possible external impacts of water projects; several examples of water diversion projects are provided to illustrate, in qualitative fashion, the possible magnitude of the external effects. Second, since interbasin transfers have an important impact on nonmarket values, ways of measuring these values for inclusion in project evaluation are considered.

The Importance of Environmental Concerns in Water Project Evaluation

Canada's large land mass and seemingly abundant supply of water has resulted in an attitude that water is costless and, in order to satisfy demand, it is simply a matter of manipulating supply. In the past, not enough consideration was given to the environmental effects of water development projects because the projects seemed, and in most cases were, small relative to their environment (Tate and Reynolds 1983).

The benefits of water development projects have often been overstated and usually achieved through social and environmental costs. There are many examples of the environmental effects that occur as a result of diverting water from its natural course. When a system that has taken millions of years to evolve is suddenly changed in a few short years, there are bound to be enormous environmental costs and other external diseconomies. Different types of projects which can disturb the natural flow of a river include dams, diversion schemes, channel regulation, dredging, dyking, change in land use, or any other undertaking which affects the runoff hydrograph (SNBB). Often planners feel that if structures are only to be built as required, the environmental effects will be minimal, but it is the experience of U.S. planners that construction creates a "domino effect". The construction of one diversion project has such great side effects, some predicted and others unforeseen, that the only solution is to construct another diversion scheme to offset the externalities created by the first. By examining the external, often nonmarket, effects from dam building alone, one gets some idea of what could possibly result from multi-structure projects such as those required for interbasin transfers.

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[10] More precisely, an externality is said to occur whenever the welfare of one economic agent is affected by the actions of another economic agent, but the latter does not take into account the effect of his or her actions on the former. If the affected agent is unable to modify the behavior of the acting agent because there are no institutional devices (e.g., markets) for doing so, this constitutes a market failure and justifies government intervention.

The High Aswan Dam. The effect of a dam is not to change the natural course of a water system but merely to regulate its flow. One of the most famous dams, the High Aswan Dam in Egypt, is an example. This dam was to provide enough water to irrigate 1.3 million acres of land and to control the annual floods of the Nile River (Bocking 1972). Only 750,000 acres of the 1.3 million acres have proven suitable for irrigation from this dam and less than half of this has actually been developed for irrigation. Much of the electricity generated by the dam is used in irrigation, while the silt that once deposited on the Nile Delta now falls to the bottom of the reservoir behind the dam (Lake Nasser), and the river now erodes the rich delta soil. In addition, a reduction in nutrients entering the Mediterranean Sea has destroyed a sardine fishery that once produced 18,000 tons annually. Although some of these externalities were not properly foreseen, construction of the High Aswan Dam appears to have reduced the overall economic welfare of Egyptians.

The Bennett Dam. Another example of environmental costs associated with dam building is the W.A.C. Bennett Dam in British Columbia. This dam was built to provide cheap hydro-electric power. The reservoir (Lake Williston) takes up 680 square miles of Canada's wilderness; included in the land covered by the reservoir were three rivers (the Finlay, the Parsnip and the Peace), support for six thousand moose, lands which the Tall Grass Indians made their living from, and a few farmers and ranchers. The area could also have provided a recreation site for thousands of people.

The builders of the dam did not realize the extent of the dam's externalities on downstream resources, particularly the devastation to the Peace-Athabasca Delta some seven hundred miles away. The one-thousand square mile Delta was one of Canada's most productive wetlands (wildlife) areas, but the dam prevented the annual spring flood. Within two years the water levels of Lake Athabasca and the Delta dropped several feet, with some of the smaller water bodies in the Delta drying up completely. The lower water levels reduced the area and the quality of habitat for the waterfowl that rested there during spring and fall migration. The muskrat population was greatly reduced because the shallower water in many lakes froze completely during winter. Commercial fishing was greatly reduced. Bison numbers also decreased as a result of declining habitat. But the main and most serious costs of this dam were felt by the 1,300 native people living in the Delta region. The muskrats and fish, which were their main source of income, were greatly reduced by a water project from which they received no benefits.

The effect the Bennett Dam had on the morphology of the Peace River was to change the natural processes of the river both above and below the dam. Water that released its sediment into the reservoir picked up sediment from below the dam causing degradation and widening of the channel. It is estimated that the Williston Reservoir, with a storage volume of 57 million acre-feet, traps 98 percent of water sediment (SNBB 1972). Where river flow is regulated by a dam, outflow channels become degradated which causes increased flow from the donor basin, resulting in lower water levels in the reservoir. The change in flow regulation resulting from the dam reduces sediment transport capacity. Reduction in transport capacity is complicated by the discharge of sediment into the main channel from tributaries, which causes aggradation in the main channel and leads to the formation of deltas at tributary junctions.[11]

The Long Lake Diversion. Peet and Day's (1980) discussion of the environmental effects of the Long Lake Diversion is a good example of the possible effects of water diversion projects. The authors point out that diversion-induced changes in downstream flow resulted in reduced habitat for fish and other water fauna, decreased nutrient transfers and biological production, disrupted fish spawning, impaired esthetics, and destroyed transportation routes. In a diversion scheme, water from one river is poured into another causing it to flow at a much faster rate. Periodic flushing, for example, from Long Lake to relieve high water levels produced ecological instability in the water bed by uprooting fauna and plant life.

In the case of the Long Lake Diversion, a 10 mile section of the Kenogami River was affected by increased and reversed flow, which affected navigation and shoreline access. Esthetics were also impaired due to flooded trees and pulpwood drifting in the river. Artificially maintained high-water levels caused shoreline problems and severe erosion. An increase in turbidity resulted in a decrease in light penetration depth, photosynthesis and autotrophic production. Some of the adjustments that had to be made as a result of high water levels in the Long Lake Diversion included shoreline protection, nonstructural cash settlements, property purchase, Longlac municipal water-intake repairs, road relocation, new flood-control and land-use regulations, inconveniences, and private property damage and loss bearing. Following project completion, there was a period of ecological and social disruption, followed by re-adjustment, and relative stability.

Large-Scale Interbasin Water Transfers. When a channel is upset by the construction of water projects, the river re-adjusts until it is again in balance with the new flow characteristics, provided the water project is not too large. The above examples illustrated some of the effects caused by dam building and a water diversion project. Now consider the environmental effects of the NAWAPA project: the reservoir in the Rocky Mountain Trench of British Columbia would eliminate communities such as Prince George and Cranbrook as well as some of the best land area in Canada. A project of this size would have permanent economic, hydrological and ecological impacts. There most likely would be irreversible effects on the environment because reservoirs would flood valleys and regional water balances would change. Wildlife habitat, recreational activities, the lifestyle of indigenous people, social and private institutions, etcetera, would be affected as a result.

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[11] It is estimated that, in 27 years, the downstream effects from the Bennett Dam will result in degradation or erosion of 15 feet in the width of the Peace River (SNBB).

These external, nonmarket effects are excluded in many B-C calculations. In the case of interbasin water transfers, including nonmarket demands for water may introduce costs which may well be greater than the costs of project construction and maintenance. To argue that these costs cannot be quantified is ;simply wrong as the U.S. Water Resources Council (1979) guidelines for project evaluation include provisions for estimating nonmarket benefits and costs using contingent valuation procedures. These procedures have been employed by Walsh, Loomis and Gillman (1984) to investigate wilderness preservation values in Colorado, and these values turn out to be quite large.

A Discussion Concerning the Estimation of the Value of Nonmarket Goods

Social and private net benefits diverge in the case where water has value in uses other than commercial ones. Water has value as a recreational resource (canoeing, fishing, etcetera) and wildlife habitat; northern fresh water also has preservation value. While the objective of greatest social value may be difficult to achieve, management strategies which ignore these other uses of water are simply inefficient from an economic perspective. The major problem to be addressed when multiple uses are considered is that of valuing these uses. Unlike values of water in agricultural, municipal and industrial uses, which can be determined in the market place, ecological, wildlife, recreational and preservation values of water are not determined in the market. These nonmarket values can, however, be ascertained using a number of techniques which are now becoming familiar to practising economists. The major tool used in this valuation of nonmarket goods is known as contingent valuation (Cummings, Brookshire and Schulze 1986).

Methods for determining the values of wildlife species to hunters (e.g., duck, elk, moose) and for evaluating recreational activities (e.g., backpacking, camping, swimming, canoeing) are well-known and can be applied quite easily. The value of wildlife habitat and the value of a "way of life" for indigenous and other peoples are more difficult to estimate, but they do have a value to others—a value similar, in many respects, to preservation value.

Preservation value includes option, bequest and existence demands. Option value is the amount of money which an individual, who anticipates that a particular site might some day provide him with a benefit, would pay to guarantee future availability of the site, even though he is uncertain as to whether he may, in fact, make use of the site's amenities. Option value is related to uncertainty in cost-benefit analysis (Graham 1981, Freeman 1984, Fisher and Hanemann 1986, Cory and

Saliba 1987).[12] However, further work into methods for empirical implementation is required. "Bequest value is defined as the willingness to pay for the satisfaction derived from endowing future generations with a natural environment" (Greenley, Walsh and Young 1981, p.657). Existence value is the amount a person is willing to pay for the knowledge that a natural environment such as a wetland is preserved in a particular state. Existence value is particularly important for northern flowing rivers.

It is important to recognize that nonmarket water uses, such as wetlands and recreation, provide preservation benefits which economists are now finding can be quite substantial. For example, Greenley, Walsh and Young found that a reduction in water quality in the South Platte River basin of Colorado due to increased mining activity resulted in a welfare loss of $61 million per year to residents in Colorado. Therefore, ignoring preservation values in the evaluation of interbasin water transfer schemes could result in a substantial misallocation of resources; in particular, it results in improper use of water.

Since Canada's northern waters constitute one of the largest fresh water supplies in the world, and also part of the largest remaining virgin wilderness and wetlands region in existence anywhere, preservation demand, particularly existence demand, is an important consideration. No studies have been conducted to determine the preservation value of the northern waters (rivers) as a future source of fresh water, an ecological regulator, a wetlands area, etcetera. Indeed, to our knowledge, there are no theoretical or empirical studies regarding the existence value of any resource.[13] Hence, there has been no research to determine the economic value of the northern waters in their wetland (including wildlife habitat) and other functions. An important function in this regard is that of species preservation, which is an area that economists are now beginning to think about (Brown 1986).

CONCLUSIONS

There are a number of proposals to divert water from rivers flowing in a northern direction to areas in southern Canada and the United States. The lowest construction cost for any of these projects is estimated at $50 billion (Pearse, Bertrand and MacLaren, p.127). However, the benefits are generally unknown and it has not been adequately demonstrated that there is a need for such massive transfers of water. It appears that there is considerable waste in current water use as economic incentives and water institutions in both Canada and the U.S. do not encourage efficient use. Further, it is likely that the construction costs may be only one component of the overall costs of these interbasin water transfer projects. A major component of costs are the loss in nonmarket values from preservation, wetlands and other demands. Some of these demands are associated with the uncertainty inherent in such projects, while others are simply due to the willingness of individuals to pay not to have wetlands or an indigenous way of life destroyed. Therefore, analysts will have a difficult task, if not an impossible one, demonstrating that the social benefits of large-scale water transfers exceed the social costs.

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[12] There is a debate regarding whether option value--the difference between option price and expected consumer surplus--is the correct measure to use in cases of uncertainty or if the correct measure is option premium--the difference between the expected fair-bet point and expected surplus. In either case, these values can be substantial (Cory and Saliba, note 17).

[13] Walsh, Loomis and Gillman may be an exception, although that study is extremely limited in scope compared to the case discussed here. Greenley, Walsh and Young, on the other hand, only considered option demand.

Finally, it is necessary to recognize that the current methods employed by analysts to evaluate water resource development projects are inappropriate for analyzing anything but very small water projects. Indeed, many researchers, including the current authors, recommend that applied general equilibrium models be used to evaluate all but the smallest water development projects. Only GE models enable one to adequately identify the aggregate social welfare impacts of a resource development project, as well as what the gains and losses to various groups in society will be. Unfortunately, a methodology for including nonmarket values, which are important in the evaluation of interbasin water transfers, explicitly in applied GE models is not well-developed at this time.

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THREE CONVERGING AND COMPLEMENTARY TECHNIQUES: ENVIRONMENTAL IMPACT ASSESSMENT, STRATEGIC PLANNING, AND UNCERTAINTY MANAGEMENT.

Dixon Thompson[1]

ABSTRACT

This paper argues that for effective planning, approval, execution and operation of large interbasin transfer schemes, two well established but evolving techniques (strategic planning and environmental impact assessment) must be combined with a third, emerging technique (uncertainty management). The combination would provide a sound basis for anticipating and avoiding mistakes and for dealing with unanticipated problems.

If corporations and government agencies were to use strategic planning to develop and evaluate alternatives and to place constraints on those which might result in problems due to environmental and social impacts, they would reduce the likelyhood of embarking on the expensive process of seeking approval for projects which could and should be stopped at a later stage.

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Environmental impact assessment has been evolving from the principal concern with describing adverse biophysical and social impacts, to the inclusion of more planning and management to avoid and mitigate undesirable effects. These planning and management systems are often based upon carefully planned monitoring programmes and steering or management committees which include proponent, government and community representatives.

Uncertainty management acknowledges the fact that it is not possible to have complete knowledge of all possible significant outcomes of a project and that there will often be significant but unpredicted impacts. Uncertainty management attempts to identify possible adverse effects of probabilistic events and uses flexible management systems and contingency planning to deal with those that do occur and with unanticipated impacts.

Recent changes and trends, and the strengths and weaknesses of the three techniques will be briefly described.

INTRODUCTION

Over the last two decades, techniques for avoiding or mitigating adverse impacts and for optimizing benefits from megaprojects have evolved from trial and error to formalised and systematic environmental impact assessments. Strategic planning and uncertainty management have also changed over the last few years and can complement some of the weaknesses in current EIA techniques. In concert, if used effectively, these three techniques should provide an adequate review mechanism for megaprojects, such as interbasin transfer of water, which has not been available to date. Even if there are good grounds for pessimism about the implementation of proposed interbasin transfer projects, sound evaluation procedures should be outlined. (Gamble 1987; Thompson and Nishi 1987)

This paper will outline the definitions of the three techniques, the changes and trends which have occurred over the past decade or so, the strengths and weaknesses of each, and will attempt to show how the three will complement each other and make up for weaknesses in the individual approaches. EIA will be dealt with first because it is the basic technique used for assessments.

ENVIRONMENTAL IMPACT ASSESSMENT

Environmental Impact Assessment (EIA) can be defined as an effort to identify environmental (biophysical and social) consequences of a project before final decisions are made and to incorporate methods to avoid or mitigate adverse impacts into planning, decision making and implementation. (FEARO, 1987)

EIA can be systematised according to the phases through which the project passes: planning, assessment, approval, post-approval and implementation, and abandonment. Or, in parallel, it can be broken down according to the phases of the EIA used on the project: inventory, prediction of impacts, development and implementation of mitigation and management schemes, and monitoring.

Changes and Trends.

Five significant changes and trends can be identified.

(1) EIA is becoming more and more involved in the post-approval processes. (Sadler 1986) Previously, it was assumed that the EIA process was completely finished once a decision to approve, modify or reject the proposed project had been reached. However, because terms and conditions were frequently imposed upon approval, it became clear that the effectiveness of the implementation of the project, with respect to the terms and conditions, was a very important part of the EIA. Hence, there is now more involvement in the post-approval stages. The recognition that monitoring is an important part of EIA is one activity that is clearly recognised as needed in the post-approval stage. (Bankes and Thompson 1980; Clark 1983; Duinker 1985; Rigby 1985) and public involvement is another (Bush 1987; Bankes and Thompson 1983)

(2) In relative terms, there is less attention paid to work on the inventory stage of EIA. (Roberts 1984) Less inventory work is required in many instances because of the improvement in the data base provided by extensive work over the last twenty years. There has also been a shift from quantity in inventory development to quality. Most specifically, techniques for the scoping of projects (Ross 1987) and the identification of valued components (Beanlands and Duinker 1983) have reduced the amount of work required for development of a suitable inventory for EIAs.

(3) Better predictions are being made in EIAs because of experience, feedback from executed projects, and improved prediction techniques. (Hecky et al. 1984)

(4) More and better mitigation and management of impacts are

being carried out. This is due to increased awareness of the importance of effective mitigation and management, increasing experience, some increase in accountability of the proponent and regulator for adverse impacts, the increasing use of specific terms and conditions for approvals, and evidence that effective mitigation and management can provide benefits to all parties.

(5) Increasingly, monitoring of projects in the implementation and operations phases is being recognized as important and is being imposed as a condition for approval. Monitoring is necessary to provide essential feedback to the manager/operator, to determine compliance with terms and conditions of approval, and to provide protection for all parties (regulator, proponent, and affected publics). (Bush 1987; Beck 1984; Bankes and Thompson 1980; Reed 1984)

Advantages

EIA is required by regulation or legislation in most jurisdictions in Canada (FEARO 1985; CCREM 1985). In all cases some form of public involvement is recommended or required. There are generally provisions for specific, detailed information to be made public. Increasingly, such impact assessments combine biophysical, social, and economic impacts, or at least those socio/economic impacts which would result, or possibly result from adverse biophysical impacts.

Disadvantages

Nine disadvantages of the current practice of EIAs can be identified. These would not apply in all cases and are changing. Some disadvantages are inherent and cannot be offset by changes within the EIA system itself. The first two disadvantages could be partially overcome with better strategic planning, the next by effective use of uncertainty management, and the other six through changes to EIA processes in combination with the other two techniques.

The first inherent weaknesses in EIA could be offset by more effective strategic planning. They are: too narrow a scope of alternatives considered too late in the process. Although many EIA procedures require evaluation of alternatives, those procedures are not always the best place to identify the wide range of options and variations that are available, to evaluate them and to make the value judgements and tradeoffs necessary to select those proposals that deserve the time and money required for more detailed consideration. Because the formal assessment procedures necessarily come only after selection of one or more alternatives, it cannot be an effectively screen every realistic alternative. Therefore, proponents are advised to find mechanisms preceding, and outside EIAs, to identify and assess impacts and possible reactions of regulators and various publics. (Environment Canada and Canadian Petroleum Association 1983)

Predicting the future is, by its very nature, an inexact science and therefore requires some technique which might be able to compensate for its inherent risk and uncertainty. (Eddy 1981; Thompson 1981; Bercha 1983; Dooley 1985). Uncertainty management may be able to assist those doing EIAs to deal with this weakness, which is the third of the nine disadvantages.

There are six problems with EIA which could be at least partially corrected by changes in EIA procedures. Inadequate funding for all aspects of EIA poses problems for all phases of the process. Consideration of funding problems should also include funding of changes to projects necessitated by problems which arise only after implementation. This is one area in which changes in the EIA processes and uncertainty management might be combined to provide an adequate solution.

Scoping (Ross 1987) has been introduced to reduce problems of excessive data collection and information overload. However, because there may be data needs determined by problems which only arise or which can only be fully assessed after implementation, scoping processes should be developed in concert with uncertainty management.

In some cases, confusion has arisen over the roles monitoring was to play as a research tool as compared to a management tool. (Krawetz, MacDonald and Nichols 1987) As the ideal research tool, changes would be observed without intervention in order to maintain the initial conditions as far as possible. Used as an effective management tool, monitoring would result in intervention to correct problems as soon as they are identified. It should be clear to all involved in an EIA whether monitoring is a management tool first and foremost and will provide data for research only as a secondary function.

In some post-approval processes there are provisions made for monitoring (data gathering) but adequate provision for careful analysis of the data is missing. Not only must the data be gathered through monitoring but there must also be specific provisions (with funding) for analysis of that data and the effective transmission of the results to affected parties.

Provisions must be made to ensure that the data gathered in a monitoring programme, and the analysis to which it is subjected, will be adequate to plan mitigation and management programmes. Further, such data and analysis must have qualities that make it suitable for dispute resolution. That is, the data, and those responsible for it, would have to be able to stand up under cross examination should that be a part of the dispute resolution mechanism. This is another problem where care in EIA procedures can be augmented with attention to uncertainty management.

It would appear that at present there are no EIA procedures in Canada which have a clear mechanism for enforcement of terms and conditions of approval. Some review procedures, such as those of Alberta's Energy Resources Conservation Board are quasi-judicial and therefore do have means to ensure compliance with terms and conditions. However, such procedures are not normally called EIAs but are supplements or parallels. The terms of a contract and/or the permits and licences required after approval of a project EIA can and do impose terms and conditions but there is no enforceable requirement that they do so for all terms and conditions recommended by an EIA. Until there is a mechanism for enforcement established, a precedent set, and effective sanctions invoked, this weakness will remain.

STRATEGIC PLANNING

Strategic planning, strategic management or long-term planning deal with medium- to long-term considerations, as opposed to day-to-day operations. These senior management responsibilities involve the setting of goals and objectives, the development of strategies to meet those goals and objectives, evaluation of the effectiveness of implementation of strategies and plans and revisions to correct problems, and finally the ability to handle any surprises which might arise.

Changes and Trends

The changes and trends in strategic planning which are relevant to improved planning for and assessment of megaprojects include a change in the understanding of what the "planning environment" is. Until recently, for planning purposes, "the environment" was the economic, political and legal frameworks within which projects had to be planned and executed. The biophysical and social environments were only considered after the fact, if at all. Increasingly however, the biophysical and social aspects of the environment are components which strategic planners try to take into consideration. (Reed 1985) This is reflected both in textbooks on strategic planning (Andrews 1980; Steiner 1979) and in government reports on economic development. (Royal Commission on the Economic Union and Development Prospects for Canada 1985; World Commission on Environment and Development 1987; National Task Force on Environment and Economy 1987)

Environmental scanning is a tool which has been introduced by some strategic planners to help keep them up to date on technical, environmental and social issues which ought to be incorporated into the strategic planning processes. Thus, such factors are weighed in the early evaluation and selection of alternatives, and not later in the EIA process.

The knowledge and awareness of the very high costs of errors in accounting for impacts on the biophysical and social environments has been leading senior executives to incorporate such considerations earlier rather than later in decision making processes. The introduction and imposition of jail sentences and much higher fines for infractions of environmental regulations have been principal factors in increasing awareness in those who had not been convinced that anticipate and avoid strategies are good business practices compared to react and cure tactics. The cancellation of projects as a result of EIA reviews and very large costs incurred in cleaning up after mistakes have been made have also been significant.

Advantages

Effective strategic planning which incorporates considerations of adverse biophysical and social impacts assists everyone involved by avoiding commitments to projects which are made on incomplete information. It is now generally understood that such factors will have to be considered sooner or later and that it is generally cost effective to do so sooner.

Strategic planning has the advantage that it is a confidential process during which the proponent can make value judgements, involving very tentative suggestions or very sensitive information. Because it takes place within a corporation or agency, there are opportunities to assess alternatives, and reject them, in a way which cannot be used in a public forum. Experts should be proposing and assessing a wide variety of possible alternatives without the inhibitions of public and media scrutiny. The majority of such proposals will be rejected without the need for any public review. Proponents will often use sensitive, confidential information such as details of financing, or position relative to industrial competition in making judgements about alternatives and are justifiably reluctant to make such information public.

Disadvantages

There are six problems with strategic planning's abilities to deal with the issues under consideration here. The first is that sometimes the processes are carried out as if the future were to be "surprise free". Efforts to incorporate every possible contingency would paralyse any planning process and those that deal with all-out nuclear war or invasions from outer space are a waste of time. However, strategic planning exercises which use one scenario or vision of the future exclusively, and which are not prepared to consider any other possible outcome, may be as wasteful. Planning which attempts to accommodate more than one plausible vision of the future, or which at least has the flexibility to react to unanticipated events or outcomes, has a better chance of avoiding the types of controversy which sometimes arise during the approval phases of EIAs.

Strategic planning is necessarily a process which is hidden from industrial competition, the government and the public. Therefore it is not surprising that it is viewed with scepticism by some members of the public. It is impossible for corporations or even government agencies to allow continuing public scrutiny of their strategic planning but corporations might make an effort to describe those processes in an EIA document in addition to describing "need" and "alternatives". That is, an understanding of how and why a project was selected over available alternatives might be useful in discussing proposals. This would only be the case if it were clear that the processes adequately considered biophysical and social consequences.

Although strategic planning and documents about planning for economic development now recognise the need to incorporate environmental considerations, that "environmental and economic concerns must go hand in hand", that "it is not possible to have a sound economy without a healthy environment" (National Task Force on Environment and Economy 1987), we are not yet very highly advanced in the required technical and management skills. There are also very heavy residuals of opinion that engineering and/or economic considerations must necessarily precede and overrule environmental and biophysical factors.

Strategic planning always faces a time frame dilemma in which more immediate concerns overwhelm longer term ones. Immediate concerns about employment, economic well being and rate of return on investment often take precedence over a problem which will only develop over the next couple of decades, or which is only a small part of a much larger cumulative impact which only reaches significant proportions over the long term. (Canadian Environmental Assessment Research Council 1986; Sonntag et al. 1987.)

In many instances, strategic planning does not understand and accommodate the role of research and development (R & D) over the longer term. R & D is important not only because even the corporation's own R & D programme can produce "surprises" but also because it should be an active part of setting goals and making plans to achieve those goals. Thus a strategic planning process which understood and used R & D effectively would try to turn an environmental problem into an opportunity to develop and market the expertise or the technology to solve that problem.

Strategic planning obviously faces the difficulty that predicting the future is an inexact science, hence the need for uncertainly management.

UNCERTAINTY MANAGEMENT

Uncertainty management is an attempt to react effectively to events which are probable but the timing of which cannot be determined (e.g. fires, floods, earthquakes, accidents) or to unanticipated events. It recognises the imperfect nature of predictions and the fact that not all future events can be anticipated. Uncertainty management techniques include contingency planning, emergency response planning, various forms of insurance, and flexibility in planning and management which permits as quick and effective reaction to the unanticipated as possible.

There are four different types of concern: unanticipated events or outcomes, hazards which can be identified but about which too little is known to understand them in any quantitative sense as to probability or magnitude, hazards which are well enough understood to be subjected to a risk assessment, and perceived risk.

Risk assessment is an objective measurement of risk obtained by multiplying the probability of the event by the magnitude of the outcome. Such a calculation necessarily requires a good database and historical record. (Wilson and Crouch 1987; Russell and Gruber 1987; Bercha 1983)

Perceived risk is a quantitative and objective measure of the feelings or fears of a population which uses well developed techniques which can be accurate if properly used (Slovic 1987). It is NOT an opinion or even an opinion survey. It is necessary to include this definition because the calculated values for risk are often contrasted with values determined for perceived risk in a population. While it is clearly possible to say that a risk assessment and a determination of perceived risk are the same or that one is larger than the other, it is incorrect to say that one or the other is wrong. They are different measurements.

Increasingly assessment is being used in policy formulation (Russell and Gruber 1987; Miller 1985).

Changes and Trends

Methods for dealing with uncertain future events have not yet developed to the stage where they are routinely employed. However, experience with them is accumulating. The most significant change which is leading to their being given serious consideration is the available information about the increasing scale and costs of unanticipated events. With each major pollution incident (Bhopal, Three Mile Island, Chernobyl, the pollution of the Rhine, Love Canal, and the "blob" in the St. Clair River) risk assessment and uncertainty management increase in importance for industry, regulators and the public. The arguments for risk assessment and uncertainty management become stronger and the data base improves. The common purchase of insurance of various forms, the implementation of workers' compensation programmes, and the increased use of emergency response planning (Bhopal Aftermath Review Steering Committee 1986a, 1986b; Canadian Petroleum Association 1987) all lend credence to the efficacy and practicality of attempting to manage risks and uncertainty.

Advantages

The greatest advantage offered by uncertainty management is the fact that it is explicit recognition of the fact that no prediction is perfect and provides at least a starting point for attempts to deal with the difficulties which that flaw causes (Jones and Greig 1985; Regier 1985; Holling 1978). The acknowledgement of Murphy's Law (what can go wrong will go wrong) provides some backup for the inherent weaknesses in EIA and strategic planning which are necessarily based upon inexact predictions. The advantage which provides the greatest incentive for the use of uncertainty management is the fact that the utilisation of the mechanisms suggested below may permit conditional approval of projects before all uncertainty has been removed, with the approval of those members of the public who could be affected.

Disadvantages

The principal disadvantages of these techniques are the fact that they are not developed to the stage that they can be used routinely with confidence, and do not have a "track record" to establish credibility. Two other problems arise from the pervasive misunderstanding of probability and of planning for contingencies. The first problem is that even in cases in which the data base is very good, such as in the case of flooding in a well understood watershed, the probability of flooding may be a sound figure but that does not mean that the event will take place according to the probability. Probabilities are not linked to events in any cause and effect relationship. The other misunderstanding is that if an event does not take place as predicted, then any time, effort and money spent in contingency planning for the non-event was wasted. Such planning for contingencies must be understood in the same way most insurance is understood: it is good to have it, but it is even better if you never have to use it.

Management of Uncertainty

If a risk assessment identifies an undesirable outcome which should be avoided or if there is a possible adverse impact (hazard) about which there is enough concern that it must be taken into consideration, there are four things which can be done in efforts to manage the uncertainty.

(1) For some anticipated adverse outcomes it is possible to have contingency plans or emergency response plans in place. For example, when sour gas wells are drilled in Alberta, if they are deemed to be critical (high concentrations of hydrogen sulphide, high pressures, and populations close enough to be affected) emergency response plans are put in place for evacuation of all people in a designated emergency response zone (with provisions for care of livestock) or ignition of the well in the event of a blow-out or significant leak (to burn the poisonous hydrogen sulphide to less toxic sulphur dioxide). Such plans will not remove all fears or other concerns (impact of sour gas facilities on property values) but it can be an effective mechanism for facilitating approval. (ERCB 1985; Bush 1987)

(2) When adverse impacts have been predicted, carefully planned and adequately funded monitoring and management programmes must be put in place so that the adverse impacts can be identified and responded to quickly, should the undesirable outcome occur.

(3) Uncertainty management requires an effective steering or management committee which includes representatives of all actors (community, proponent and regulator), has adequate funding and

includes a dispute resolution mechanism. A sunset clause might also be desirable (Beck 1984; Bush 1987)

(4) Some specific mechanism must be available to ensure that adequate remedial action can be taken should unplanned for adverse events take place. Such funding mechanisms as insurance schemes, performance bonds or sinking funds would provide communities with assurance that remedial action would be taken if they acceded to an approval before all uncertainty about their concerns had been removed. Such funding mechanisms have the advantage of making legitimate community concerns a reality for skeptics within the proponent's organization who might not otherwise take the issue seriously enough.

There will likely be major difficulties in getting all parties (proponent, community and regulator) to agree on which uncertainties deserve serious consideration. Similarly, there will be problems in arriving at agreements as to how much funding should be made available for dealing with uncertainties and how it should be administered. Performance bonds are often required to ensure compliance with environmental regulations but these are used when the criteria to be used to judge performance are specified (e. g. strip mine or pipeline right of way rehabilitation). These difficulties will only be eased through sensitive negotiation and experience.

CONCLUSIONS

There are no theoretical or political grounds on which to rule out interbasin transfers absolutely. However, most if not all megaproject interbasin transfers have not been subjected to rigorous EIA or have exhibited very significant adverse impacts after implementation, which were not adequately understood when approval was granted. Examples of such unanticipated adverse impacts have been provided in the papers at this conference by Kellerhals, Day and Hecky.

The types of uncertainty which have arisen in Canada include the legitimate efforts by natives to claim rights (land or harvesting of renewable resources), morphological changes in reservoir shoreline and downstream from diversions, changes in vegetation and land use downstream from diversions, changes in water quality due to mobilisation of mercury or transfaunations, or changes in demand (for energy, agricultural products, recreation).

The research needs have been implied in this paper in the statements about advantages and disadvantages of EIA, strategic planning and uncertainty management.

The strength of strategic planning is the opportunity to review proposals thoroughly before commitments are made to alternatives which suffer from major flaws. This will require more work on how to incorporate effectively biophysical and social concerns into decision making. Improvements in EIA could be made through research on how to set and enforce terms and conditions for approval, with due consideration for accountability and effective management of uncertainty. Risk assessment and uncertainty management are the areas in which the most research is required and in which improvements will likely be realised only as fast as experience is gained and evaluated. Work is needed on identification and evaluation of uncertainty (how do we evaluate the limitations of predictions of the future?); the establishment and operations of steering or management committees which include representatives of the affected communities, the proponent and the regulator; and the setting and management of funding mechanisms for uncertainty management.

The suggestion that uncertainty management play any role at all in project evaluation will be criticised because of the value judgements involved, and the fact that proponents may be required to deal with issues that are very poorly understood. In the short term the criticism is valid. However, it should be very clear by now that the inability to predict the impacts of megaprojects with certainty has led to many very serious problems for communities, proponents and governments involved. Therefore, the issue deserves careful attention. It must also be recognized that value judgements are rendered on a routine basis with respect to the uncertain future and are well accepted by Canadian society. At this conference, Day pointed out that the Kemano power project was built inside a mountain at very considerable expense as a contingency in the event of war, and that the towers on the transmission line were doubled in an effort to reduce the impact of avalanches. In Canada, safety codes, fire and building codes, engineering safety factors, planning to avoid flood damage, and contingency planning for disasters, are routinely required by legislation and fully accepted as reasonable costs to be incurred in efforts to provide an environment which is "safe". Safe is a value judgement and not a scientific concept.

Implementation of the above proposals can be required through legislation and regulation as far as EIA is concerned. It will not be possible to legislate requirements for the effective use of strategic planning. However, it is no longer as difficult as it once was to provide good evidence that inclusion of environmental (biophysical and social) concerns in strategic planning is prudent and cost effective. Implementation of risk assessment and uncertainty management will necessarily be tentative and slow because of the lack of experience, but should eventually become as routine as our efforts to deal with storms and fires and floods.

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DEVELOPMENT OF A FIXED HORIZONTAL SCREEN TO PREVENT TRANSBASIN FISH TRANSFER

P. L. JOHNSON[1] and S. J. GRABOWSKI[2]

ABSTRACT

An irrigation project was proposed which would transport water from the Missouri River drainage into the Hudson Bay drainage. The potential for introduction of fish species into the Hudson Bay drainage and options to prevent such an introduction were studied. Four fish species, rainbow smelt (*Osmerus mordax*), Utah chub (*Gila atraria*), gizzard shad (*Dorosoma cepedianum*), and common carp (*Cyprinus carpio*), were identified for control. Because these species could not be controlled discriminately and because all developmental stages would be present during part of the operating season, it was necessary to develop a fish control that would prevent downstream migration of viable adult fish, fish larvae, and fish eggs. Numerous alternative control techniques were considered. A fine mesh, fixed, horizontal screen was selected for development. Laboratory tests were conducted to evaluate the filtration effectiveness of the design (using live eggs and larvae), to develop sizing guidelines based on geometry and discharge, to evaluate self-cleaning features, and to assist in design and development of hardware (spray cleaning systems, seals, screen inspection, and repair techniques). In addition, a field test site was used to evaluate fouling and cleaning, corrosion and materials, accessory equipment performance, maintenance needs, screen wear, and debris types and quantities. Although an effective screen design was developed, a reauthorization plan for the project has reduced the project's size eliminating all irrigation in the Hudson Bay drainage.

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INTRODUCTION

In August of 1965, the Congress of the United States authorized construction of the initial stage of the Garrison Diversion Unit of the Missouri River Basin Project. Initial stage objectives of the U.S. Bureau of Reclamation project were to irrigate about 100,000 hectares (250,000 acres), supply municipal and industrial water to several towns and cities, and supply water for fish and wildlife and recreation purposes at numerous sites. The water with a discharge of up to 55 m^3/s (1950 ft^3/s) would be withdrawn from the Missouri River and delivered through a series of pumping plants, reservoirs, and canals. The land to be served was in the Souris, Sheyenne, James and Wild Rice River drainages in east-central North Dakota. The James River is a tributary of the Missouri River. The Sheyenne, Wild Rice, and Souris Rivers all lie in the Hudson Bay drainage. In addition, several isolated closed-basin areas in North Dakota (that generally contain shallow lakes and marshlands which have great importance as habitat and breeding areas for waterfowl) would receive water.

Concern was expressed that certain species of fish found in the Missouri River Basin, but not in the Hudson Bay Basin, would gain easy access to the Hudson Bay Basin through project features, and that their survival, reproduction and subsequent proliferation would have an undesirable and detrimental effect on the sport, commercial, and Native Indian fishery of Lake Winnipeg. It was also suspected that the project will provide a means by which fish could migrate into North Dakota waters they presently do not occupy and eliminate the effectiveness of the waters as waterfowl breeding areas.

A review board (International Garrison Diversion Study Board, 1976) listed 10 fish species that could produce adverse impacts. Four species from these 10 that have the greatest potential for adverse impacts were identified. These four species were: rainbow smelt (Osmerus mordax), Utah chub (Gila atraria), gizzard shad (Dorosoma cepedianum), and common carp (Cyprinus carpio). Because these species could not be controlled discriminately and because all developmental stages would be present during some part of the project operating season, it was deemed necessary to develop a fish control that would prevent downstream migration of viable adult fish, fish larvae, and fish eggs. Survival of the fish, fish larvae, and fish eggs (after filtration from the flow) was not a requirement, nor was it even desirable.

Operational techniques, poisons, violent hydraulic action, electrocution, ultrasonics, ozone, and extreme high or low pressures were all considered as potential control options. They were all found inadequate either because of safety considerations for humans and wildlife, cost, or because they could not achieve the objective control. Various screening or filtering options were then considered. Two alternatives were found that appeared to supply adequate control. A rapid sand filter could more than achieve the desired control; however, cursory designs revealed that a sand filter capable of handling the maximum canal discharge of 55 m^3/s would have a prohibitive cost. Laboratory testing also indicated a potential for egg and larvae passage during the transition from back flushing to the filtration mode of operation. A fixed horizontal or slightly downward sloping screen (figure 1) was also thought to be able to yield the required filtration. The screen mesh would be selected sufficiently fine to meet the filtration requirements. Seals around the fixed screens would be made watertight. Previous field experience indicated that this type of structure has good self-cleaning features. The screen weave is so fine (24 to 80 mesh or 24 to 80 wires per inch or 945 to 3150 wires per meter) that the screen has a slick, fabric-like texture. Openings in the screen are generally small enough that debris will not cling to individual wires. The basically tangential flow across the screen sweeps the debris down the screen surface to where it accumulates at the point where the last of the flow drops through.

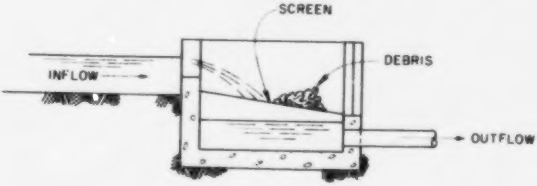

Figure 1. - General fixed screen concept.

Previous installations of fixed horizontal screens had been used for relatively small discharges, less than 2.8 m^3/s, with the objective of either filtering weed seed from irrigation water, collecting biological samples from small streams, or filtering industrial intake water. A major effort was required to develop a design that would meet the needs of the Garrison Project.

With the assistance of a hydraulic model study that considered discharge, dimensional, and self-cleaning characteristics of the screen (Johnson, 1975) an initial design was developed. This design featured 40-mesh fine screen supported by a 2-mesh screen with both screens attached to a framework using a clamp bar arrangement. Each screen frame was sealed into the structure with rubber compression seals. The design was then reviewed by the International Garrison Diversion Study Board, a board with biological and engineering subcommittees comprised of one-half American and one-half Canadian members. Their review yielded several criticisms (International Garrison Diversion

Study Board, 1976) that required further study. A task force was then formed in the Bureau of Reclamation to guide the studies and to direct the structure redesign. The task force membership included representatives of Design, Operation and Maintenance, and Research. Both engineers and biologists were represented. The task force, with input from a team of consultants, identified the critical design criteria that stipulated that the screens, the structure, and the seals between the screen and structure must allow no leakage or organism passage; that the design should include sufficient redundancy to ensure satisfactory filtration even with partial failure; the design should minimize the demand on operation and maintenance personnel and should be as foolproof as possible; the design should be durable and should have sufficient strength to withstand complete fouling without failure; and the design should include sufficient cleaning and debris removal facilities.

Considering these criteria the screen was redesigned. This new design was tested extensively in both the laboratory and field with the objective of refinement and verification. The studies conducted are documented in detail in a Bureau of Reclamation report dated December 1982.

MATERIAL AND METHODS

Laboratory Studies

Initial laboratory studies used a small standpipe model to make preliminary evaluations of the filtration potential of different screen materials. This model had a constant head control box supplying water to a vertical pipe. Screen samples were placed across the pipe and were exposed to water velocities comparable to the maximum velocities in the prototype. All flow passing through the screen was filtered through a 102-micrometer plankton net. Smelt eggs and larvae were injected into the flow above the screen and the model ran for 45 minutes. The plankton net's contents were then examined to determine if any passage occurred.

Laboratory effort then concentrated on use of the sectional model (figure 2). This model simulated a full-scale cross-sectional slice from the prototype structure. It was 0.9 m wide and contained one full screen panel which allowed evaluation of the fine screen which was selected from the standpipe test, the screen retention design and the panel seals. Water entered the head box, passed over the headwall, dropped through the screen and into the tail box. A large plankton net was placed in the tail box to refilter all flow passing through the model. Eggs and larvae were injected into the flow above the headwall. The eggs and larvae were stained to assist in recovery.

The model was run for 45 minutes. The material accumulated in the plankton net was then examined to evaluate the filtration effectiveness. Discharges ranging from 0.085 m^3/s to 0.510 m^3/s were studied using a randomized test schedule. Where possible a typical test used 10,000 eggs and/or 10,000 larvae. Live organisms were preferred for testing; if they were not available, formalin preserved specimens were used. A total of 119 tests were conducted. The sectional model was also used to observe hydraulic characteristics of the screen, to conduct testing of alternative screen cleaning devices, to study the sealing characteristics of the frame seals and to consider other design refinements.

Figure 2. - Laboratory model.

FIELD STUDIES

Test Facility Considerations

A sectional model or test facility was constructed at Lake Brekken, near Turtle Lake, North Dakota (figure 3). This field model was similar in concept to the laboratory sectional model in that it represented a full-scale slice from the proposed structure. The field facility, however, was 1.8 m wide, or wide enough to contain two full screen panels. The facility was supplied water by a feeder canal which branched off the McClusky Canal, the principal supply works for the Garrison Project. During testing the only water passing through the canal was the water supply for the test facility. This water was quite eutrophic. It was expected that with the larger flows required as the project became operational, the eutrophic water presently in Audubon Lake would become less productive as it was diluted with the more oligotrophic Missouri River water. Therefore, the quality of the field test facility water supply yielded a severe test of screen performance. The field facility was primarily used to study operation and maintenance-related problems, such as fouling and cleaning, corrosion and materials selection, and accessory equipment evaluation. Accessory equipment being tested included traveling screens, vibrating screens, spray cleaning systems, automation devices, and debris handling systems. The field test facility has operated intermittently from 1979 through 1987. The facility has operated for approximately 10,000 hours and has screened approximately 15,000 acre-foot of water. The longest period of continuous operation was approximately 6 months.

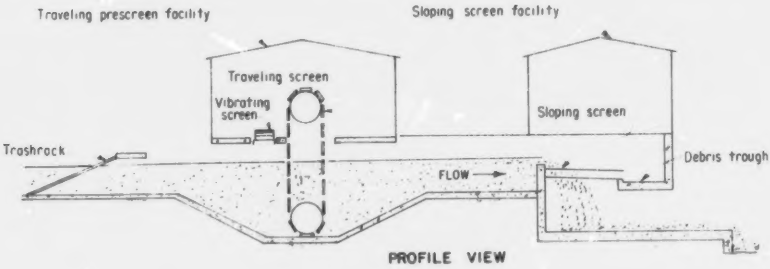

Figure 3. - Field test facility.

Initial designs of spray cleaning systems that had been studied briefly in the laboratory were tested and refined in the field test facility. The spray cleaning device tracked upstream and downstream below the screen panels. The device contains a manifold into which is placed a series of nozzles that create flat fan-shaped jets. These nozzles spray up on and through the bottom sides of the operating screen panels. Fouling material is dislodged by the spray and then swept away by the flow over the screens. Field use allowed testing under more representative fouling conditions than experienced in the laboratory and also exposed the cleaning mechanism to the environmental conditions under which it would operate in the prototype. The spray cleaning system effectively cleaned the screens. Weaknesses in the mechanical design which led to drive system failures or excessive maintenance were identified and corrected. Automatic controls for the cleaning system were developed.

Corrosion and materials selection were studied. Material failures which lead to mechanical failures and excessive maintenance were found. In particular, two screen materials were tested in conjunction with the stainless steel frames. Phosphor bronze 70-mesh screen which has 90 percent copper was tested to determine if the algicide property of copper would yield useful antifouling traits. The phosphor bronze, however, has poor galvanic characteristics in conjunction with stainless steel. Therefore, tests were conducted both with and without cathodic protection. Also, Monel screen was tested in conjunction with the stainless steel frames. Monel, which is 70 percent nickel and 25 percent copper, should have excellent corrosion resistant characteristics.

Wear in the 70-mesh screen was evaluated using macrophotographs taken at specific locations immediately after screen installation and after specified intervals of operation. These photographs were examined and the dimensions of openings randomly measured. The dimensions were analyzed statistically and the size distribution defined. The opening size distribution for new and used screen was compared to evaluate wear due to abrasion, corrosion, or other forces. Opening size was also compared to laboratory measured egg and larvae size distributions.

The need for, the dependability of, and the operation of, trashracks and traveling screens positioned upstream of the horizontal screens were evaluated. In the field model, horizontal screen operation was evaluated both with and without use of prefiltration by a vertical traveling water screen mounted with 70-mesh screen. Likewise, horizontal screen operation was evaluated both with and without use of a trashrack with 32-mm free spacing between bars.

Debris handling and removal were evaluated. Debris filtered by the horizontal screen was transported to a disposal lagoon by use of sewage chopper pumps and pipe transport. A vibrating screen mounted with 80-mesh screen was used to reduce water content of the debris collected on the horizontal screens. Coarse debris collected on the trashracks was handled manually, but automatic trashrack rakes would be used in the prototype structure.

Biological and Water Quality Considerations

A monitoring program was established for the field test facility. Included was water quality analysis, biological analysis as related to screen loading and deterioration, and other environmental monitoring. Water quality analyses included major cations and anions, trace elements, and nutrients. Water samples for analysis were collected at three sites at noon and midnight on Mondays and Thursdays during the operation of the field test facility. Twice each day phytoplankton and zooplankton samples were collected upstream of the traveling water screen, between the traveling screen and the horizontal screens, and below the horizontal screens, for laboratory identification and counting.

Fish and invertebrates were sampled at random times from the horizontal screens and from the debris sumps to establish a partial list of species in the canal. Samples for determination of dry weight biomass were collected at the three previously described sites.

FINAL DESIGN

Figure 4 shows the final proposed horizontal screen panel and seal design. The design shown is for the horizontal screens and their immediate structure. The framework will be fabricated from stainless steel to minimize corrosion and maintenance requirements. Corrosion-free seating surfaces will help to assure a positive seal. The frame has also been designed to withstand, without failure, complete screen plugging with pooled water above the screens.

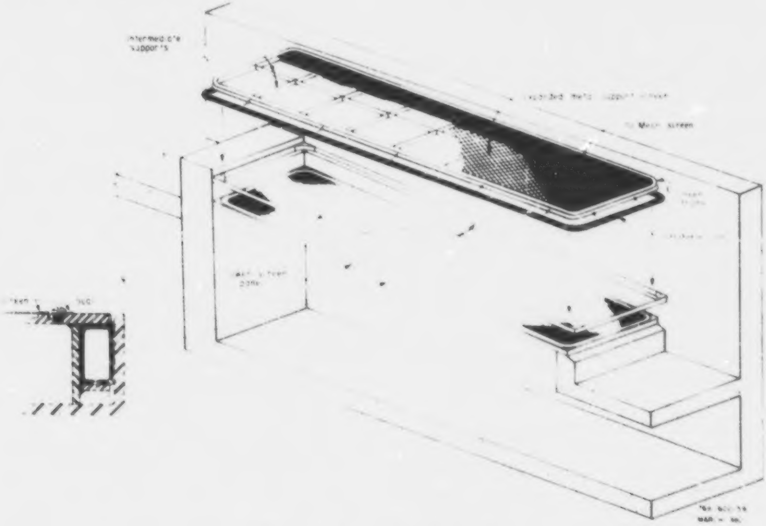

Figure 4. - Final design.

The originally proposed 2-mesh support screen was replaced by stainless flattened expanded metal, which was welded to the frame. The design adds strength to the screen panels while allowing leakproof attachment of the fine screen to the frame. Studies revealed that the expanded metal caused little reduction in the discharge capacity.

The screen is attached to the frame in a manner similar to attachment of screen to screen door or window screen frames. The screen is pressed into a machined groove and retained in that groove with a 3.2-mm-diameter rod. A 3.2- x 12.7-mm cross-section bar is placed over the retaining rod and screwed down securely. This design yields a positive, leakproof attachment of the 70-mesh screen to the frame. However, considerable time, manpower, and conscientious effort is required to install the screens.

The pneumatic or inflatable seals, which supply a watertight seal between the screen frames and embedded framework, have proven to be an excellent feature. They seat over a wide area and are not sensitive to minor irregularities in the seating surface or to bits of debris on the seating surface. In addition, the design is not sensitive to warping in the welded framework. The seals allow quick screen panel installation and removal with a minimum of demand on maintenance personnel. The seals depend on a reliable pressurized air supply and require an air distribution line. The design allows quick connect and disconnect of individual panels. An alarm system guards against unacceptable loss of pressure in the individual seals and excessive airflow in the main air supply line. A storage tank assures adequate compressed air supply in the event of a power failure. It has been found that adequate sealing can be obtained with an air pressure of 83 kPa (12 lb/in^2) gauge. An arbitrary operating pressure of 152 kPa (22 lb/in^2) gauge was established with a minimum acceptable pressure of 124 kPa (18 lb/in^2) gauge. The pneumatic seals have proven to be very durable and dependable.

Also included in the design was a second similar screen panel 0.3 m below the service screen. This screen functions as a backup in case of damage to or failure of the service screen. The service screen with its expanded metal frame also functions as protection for the backup screen. The service screen pneumatic seals are on separate air supply lines from the backup screen. To date, the screen material has proven durable.

Laboratory Study Findings

Results from the standpipe model revealed that 60-mesh screen with 0.190-mm-diameter wire and 0.234-mm-square openings retained or filtered out all eggs and larvae of the designated fish species. Seventy-mesh screen with 0.165-mm-diameter wire and 0.198-mm-square openings was therefore selected for inclusion in a conservative design.

All sectional model tests have demonstrated the 70-mesh screen and design concept to be an effective filter which prevents the passage of eggs and larvae of the species of concern. A total of 119 tests were run using 532,000 preserved smelt larvae, 410,000 preserved smelt eggs, 169,000 live smelt larvae, 50,000 live smelt eggs, 207,000 preserved chub eggs, 28,000 live chub larvae, 40,000 live chub eggs, 50,000 live carp eggs, 100,000 live shad larvae, and 30,000 live shad eggs. No intact egg and/or larvae passage was observed.

With clean water the screen was found to have a maximum discharge capacity of 0.465 m^3/s per meter width or 0.425 m^3/s per screen frame. Laboratory sectional model studies have also shown that effective screen cleaning can be obtained with a traveling spray cleaning system. Findings indicated that this device could be effective either spraying down from above or up from below onto the operating screen. More details on this design are included with the field study findings.

Field Study Findings

The horizontal screen design with pneumatic seals, with an automated spray cleaning system, and with a pumped debris handling system was found to be functional. The pneumatic seals were very effective and appear to be an outstanding design feature. The spray cleaning system was likewise found effective. It was found that for the specific spray cleaning system design (specific plumbing, manifold, and nozzles), adequate cleaning was obtained with an operating water pressure of 207 kPa (30 lb/in^2) gauge. An air cylinder, cable-pulley drive system for the automated traveling spray cleaner required substantial refinement to eliminate material wear and component failure. The spray system was developed into a dependable well-functioning unit.

The effective spray cleaning system negated the need for the phosphor bronze material originally selected for its algicide properties. In addition, macrophotographs have shown pitting and deterioration of the phosphor bronze while the Monel showed very little deterioration. The phosphor bronze screen experienced reduced discharge capacities overtime. Consequently, Monel screen was selected for use in the final design.

It was also found that debris loading was the major factor that controlled discharge capacity. As debris loading became heavier, screen fouling occurred at an increased rate. Increased fouling reduced local flow through the screens and caused the water to flow farther down the screen before it fell through. The screens were cleaned when water began to flow over the downstream end and into the debris trough. Consequently, as debris loading increased the time interval between spray cleanings decreased. When debris loading got so heavy that cycling the cleaning device at a minimum acceptable interval proved insufficient, discharges were reduced. Under high debris loading conditions, such as in midsummer with the Aphanizomenon load, discharges were greatly reduced. Continuous discharges of up to 0.279 m^3/s per meter width of screen were obtained in spring and fall while midsummer discharges dropped as low as 0.062 m^3/s per meter width of screen. Both of these discharges were considerably below those observed in the laboratory.

For the types of debris that have been encountered in the canal water the vertical traveling screen is ineffective in prefiltration. Use of the traveling screen results in very little improvement in the horizontal screen discharge capacity. The trashrack does not increase discharge capacity but does prevent large debris from moving onto the horizontal screens.

The pumped debris handling system has proven successful. The commercially available vibrating screen has also been used successfully to dewater this debris.

Water quality analyses for complete chemistry, trace elements, and nutrients were conducted. Generally, the canal water had a pH around 8.4 and conductivity around 1,100 to 1,200. Copepods were far more abundant that cladocerans in zooplankton samples, although rotifers were also relatively abundant. Aphanizomenon dominated phytoplankton samples for most of the season. Anacystis numbers per mL began to increase around the end of August.

Brook stickleback (Culaea inconstans) and fathead minnows (Pimephales promelas) were the dominant fish species at the field test facility. Some other species collected were black bullhead (Ictalurus melas), black crappie (Pomoxis nigromaculatus) and freshwater drum (Aplodinotus grunniens).

Macroinvertebrates collected at the field test facility included water boatman (Corixid trichorixa), predaceous diving beetle (Dytiscus sp.), chironomid larvae, whirligig beetles (family Gyrinidae), snails and horsehair worms (phylum Nematomorpha).

The macrophotography analysis of size distribution of screen openings and of fish eggs and larvae found that the typical openings in new, 70-mesh, Monel screens were approximately 0.195 mm by 0.213 mm with standard deviations of approximately 0.018 mm. Used, 70-mesh Monel screen had typical openings of 0.200 mm by 0.213 mm with standard deviations of approximately 0.017 mm. It thus appears that screen use (4,000 hours or one season) has little detectable effect on screen opening size. In comparison, measured fish eggs (which varied in diameter due to both species and source) were 3.4 to 7 times the size of the screen openings. For larvae, it was noted that the critical dimension with respect to screen passage was head width or body depth, whichever was greater. Because larvae could align with screen openings, length was not considered a critical dimension. Measurements indicate that larvae are the critical life stage with respect to screen passage with head widths or body depths running 2 to 4 times screen opening size.

Tests were conducted to evaluate the durability of various repair techniques for 70-mesh Monel screen. Lead-tin solder, silver solder, and epoxy patches were placed on Monel screen. The screen was exposed to high-velocity sprays. After a few hours epoxy patches began to fail. Silver solder patches failed after 400 hours, while lead/tin patches never did fail even after 900 hours of exposure.

Along with the final design a recommended operating criteria was developed. This is a critical aspect of the entire concept. Improper operation and, in particular, improper maintenance could lead to filtration failure. Operation and maintenance personnel were directly involved in structure development. The structure was designed to minimize failure. Design improvements were also intended to lessen maintenance needs. Efforts were made to recognize and correct potential failure points in maintenance routines. Maintenance personnel would require extensive training and programs should be established to assure maintenance quality control.

In part due to environmental concerns and in part due to budgetary restrictions, the Garrison Diversion Unit has been reauthorized and reduced in size. The reauthorization allows irrigation only in the Missouri River Basin, while expanding the role of the Bureau of Reclamation in providing municipal and industrial water to 130 communities in North Dakota. Likewise it does provide for small municipal and industrial releases into the Sheyenne River.

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MODELLING OF GREAT LAKES WATER LEVELS

L. Wong[1], J.A. McCorquodale[2], and M. Sanderson[3]

ABSTRACT

A systems approach to manage the water resources of the Great Lakes is important because there are many physical, environmental, social and economic factors which affect the quantity and quality as well as the beneficial uses of water. All of these factors must be considered in developing master plans for regional water resources management. The development of such plans requires systems optimization involving the maximization of benefits and minimization of costs, subject to the contraints on the system such as the limitations in water quantity and quality and the conflicts of interests in water resources utilization. The complex nature of this optimization problem means that a sophisticated systems model is required to handle the analytical requirements. The model should be able to quantify the effects of all relevant factors on Great Lakes water resources utilization. Since many of these factors may change over time, it is necessary to build into the systems model the flexibility for accommodating future changes. This aspect of model development is especially important if the model is to be used in long term water planning. The present paper describes a Great Lakes Water Resources Model (GLWRM) which may be used as a tool for water resources management planning in the Great Lakes region. The GLHRM includes several physical and economic submodels because of the need to combine scientific, social and economic consideration in the water resources management decision making process.

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INTRODUCTION

Although the storage of fresh water in the Great Lakes Basin is immense, this does not mean that there are no water resources related problems. Over the last two decades, concern has been expressed about many water quantity and water quality problems in the basin. Some of the more important problems include - shoreline flooding and erosion; navigation; hydroelectric power development; wetlands preservation; fish habitat management; interbasin transfer of water; point source discharge of pollutants; non-point source pollution; transboundary pollution; toxic chemicals; and safe drinking water.

Recognizing that the prerequisite for optimal management of water resources in the Great Lakes Basin is dependent upon our ability to understand the behaviour of the system both at the present time and in the future, it is useful to rely upon a systems modelling approach to address the water resources problems in the region. This approach permits comprehensive analysis of problems by considering all majors factors affecting Great Lakes water quantity and quality. Development of such a Great Lakes Water Resources Model (GLWRM) is difficult, time consuming, and requires extensive efforts by many people with different backgrounds and expertise. For these reasons, attempts were made to review and identify the best models available from the literature. The models selected were then integrated to form the GLWRM which was used in addressing both short term and long term water resources management problems in the Great Lakes Basin.

The GLWRM was designed to include several physical and economic submodels because of the need to combine scientific, social and economic considerations in the management decision making process (Figure 1). The water quantity component of the GLWRM has three submodels: basin runoff, net basin supply, and hydrologic response models. It produces outflows and water level data as the final output for Lakes Superior, Michigan, Huron, St. Clair, Erie, and Ontario. These output data are required to drive the water quality and economic components of the GLWRM. In the water quality component, the pollution and environmental impacts submodels are used to estimate the environmental fate and effects of contaminants in the Great Lakes system. Finally, the economic submodels (coastal, navigation and hydro-power) allow economic assessment of some of the impacts of water quantity and quality changes.

One of the key considerations in developing the GLWRM is that, since the model is designed to be a water resources management and planning tool, it must be able to handle both short term and long term problem analysis requirements. Although it is reasonable to assume that the conditions in the Great Lakes Basin will remain the same over a short

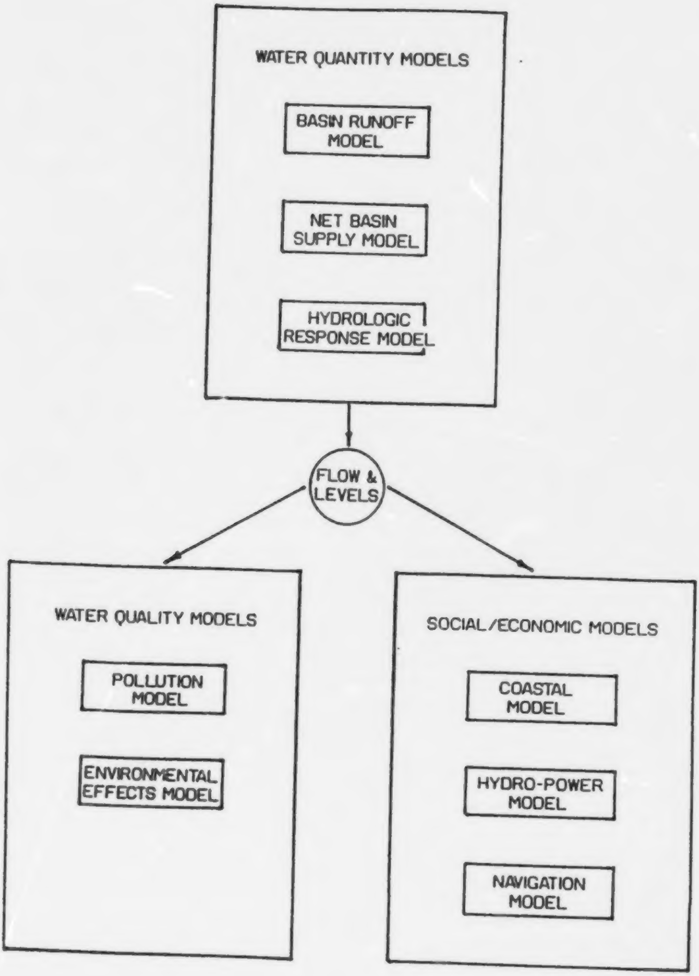
WATER QUANTITY MODELS
BASIN RUNOFF MODEL
NET BASIN SUPPLY MODEL
HYDROLOGIC RESPONSE MODEL
FLOW & LEVELS
WATER QUALITY MODELS
POLLUTION MODEL
ENVIRONMENTAL EFFECTS MODEL
SOCIAL/ECONOMIC MODELS
COASTAL MODEL
HYDRO-POWER MODEL
NAVIGATION MODEL

Figure 1 Great Lakes Water Resources Model (GLWRM)

period of time, changes are anticipated over the long term. Therefore, the GLWRM must be able to respond properly to the changing conditions within the Great Lakes Basin.

Of all the possible future changes, climatic change is considered to have the greatest potential impact on water resources in the Great Lakes Basin. Not only will climatic change affect the supply of fresh water in the region directly, it will also create many indirect or secondary pressures on water resources utilization.

Climatic Change

In recent years, there has been a growing consensus within the scientific community that global climate may undergo changes over the next several decades as a result of human activities. Concern over global climate change has arisen because of the observed changes in the composition of the earth's atmosphere. The concentration of some trace gases in the troposphere, notably carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and chloroflorocarbons (CFC) are increasing. These gases, while permitting short-wave solar radiation to reach the surface of the earth, absorb some of the long-wave infrared radiation that the earth emits back to space. As a result of the disruption in radiation balance, more heat energy is retained by the earth atmosphere system. This phenomenon is comparable to the warming of air in a greenhouse and is therefore commonly referred to as the "greenhouse effect". The gases which are known to play a role in causing the greenhouse effect are called greenhouse gases. It is generally believed that human activities such as the burning of fossil fuel, deforestation, and urban and industrial developments are responsible for the observed increase in the concentration of greenhouse gases in the atmosphere.

The possibility that the increase in carbon dioxide in the atmosphere would ultimately produce changes in the global climate was first suggested by Arrhenius (1886) and Chamberlain (1899). By the late 1970's, a considerable body of scientific knowledge has become available in the literature pertaining to the greenhouse effect and climatic change (Marland and Rotty, 1979). To appreciate the significance of the greenhouse effect on global climate, it is important to realize that all climatic processes are energy driven. As a result of the greenhouse effect, more energy will be available and therefore changes in many climatic processes are inevitable. While there is little doubt that there is an increase in greenhouse gases concentration in the atmosphere, scientists disagree on the nature and seriousness of the problem, since there are many sources of uncertainty in predicting climatic change.

$2XCO_2$ and Great Lakes Climates

Since the 1960's, many mathematical models have been developed to estimate surface temperature responses of the earth to a doubling of CO_2 ($2XCO_2$). The three-dimensional general circulation models (GCMs) are the most comprehensive models available for estimating CO_2 induced surface temperature changes. These models take into consideration the conservation of mass (air and water vapour), heat energy (sensible and latent heat), and momentum (pressure and wind) in three dimensional space (Manabe and Wetherald, 1975).

Although there is a scientific consensus that increased levels of greenhouse gases corresponding to a doubling of atmospheric CO_2 concentration would cause global warming in the order of 1.5 to 4.5 °C, there is no consensus about the impacts of climatic change. Concerns have been expressed, however, that climatic change may result in serious global and regional problems. A few examples of these problema are listed below -

- direct physiological effects on living organisms;
- potential lost of coastal areas due to anticipated global sea level rises;
- impacts on water resources and utilization of these resources;
- disruption of world agriculture due to changing precipitation patterns; and
- disruption of precipitation and evaporation patterns may result in the destruction of many natural habitats and ecosystems.

On the other hand, there has been suggestions that in some areas, climatic change may in fact enhance economic opportunity. For example, agricultural productivity will be improved in the areas where the growing season becomes longer and more soil moisture becomes available due to an increase in precipitation. In the Great Lakes region, shipping in the winter months may become possible under a warmer climate.

In recognition of the impacts of climatic change on society, Canada established a Canadian Climate Program (CCP) in 1978 to integrate the efforts of various federal and provincial agencies as well as the universities and the private sector in the field of climatology. The Atmospheric Environment Service (AES) of Environment Canada was given responsibility as the lead agency for the program. The Canadian Climate Centre (CCC) within AES was primarily responsible for identifying suitable climatic change scenarios for impacts assessment.

In September of 1984, outputs from two GCMs - the Geophical Fluid Dynamics Laboratory Model (GFDL) and the Goddard Institute of Space Studies Model (GISS) under a 2XCO2 scenario were approved for use within the CCP. With the climatic change scenarios formally established, efforts were made to assess and identify the potential social and economic impacts. Because the Great Lakes basin is one of the most important regions in Canada in terms of population, water resources, industrial and economic activities, special attempts were made by the Atmospheric Environment Service of Environment Canada to assess the impacts of climatic change within the region (Cohen, 1986).

Using the GFDL and GISS models, researchers at the Canadian Climate Centre produced regional averaged climatic data for the Great Lakes Basin. The data consisted of 1951-1980 monthly "normals" of temperature and precipitation as well as projected "normals" under $2XCO_2$ conditions as suggested by the GFDL and GISS models. The data were modified for use in the present study. Table 1 shows the climatic change factors under the GFDL and GISS scenarios for Lake Erie.

Basin Runoff Modelling

When moisture-bearing air masses move through the Great Lakes Basin, some of the moisture will be deposited in the form of rain, snow, hail or sleet. A portion of this precipitation falls directly on the surfaces of the Great Lakes and immediately becomes part of the stored fresh water. On the other hand, precipitation that falls on the land may return to the lakes as surface runoff, infiltrate the soil and become groundwater, or return to the atmosphere by evapotranspiration. The principal objective of basin runoff modelling is, therefore, to quantify the environmental fate of the precipitation that has been fallen on the land portion of a drainage basin.

The Great Lakes Environmental Research Laboratory (GLERL) has proposed a Large Basin Runoff Model (LBRM) for use in estimating basin ruoff to the Great Lakes (Croley, 1983). The LBRM is an interdependent "tank-cascade" model. Detail descriptions of the model, including the governing equations, analytical solutions to the equations, data requirements, input format and output structure, model calibration, and model applications are all available (NOAA, 1982, 1983,1984). The LBRM was used to simulate basin runoff for Lakes Superior, Michigan, Huron, St Clair, Erie, and Ontario under the following scenarios.

(1) BOC (Basis of Comparison) - Historical daily hydrometeorological data (from January 1, 1956 to December 31, 1983), obtained from the Great Lakes Environmental Research Laboratory, were used to generate daily basin runoff for the Great Lakes. This LBRM output data set was used as the basis

TABLE 1 LAKE ERIE DRAINAGE BASIN 2XCO2 CLIMATIC CHANGE FACTORS

	SCENARIO GFDL				SCENARIO GISS			
	LAKE		LAND		LAKE		LAND	
	TEMP °C	PRECIP %	TEMP °C	PRECIP %	TEMP °C	PRECIP %	TEMP °C	PRECIP %
JAN	1.8	100.0	1.9	99.5	5.8	112.8	5.9	112.6
FEB	5.1	156.3	5.1	155.2	5.5	112.8	5.6	112.9
MAR	2.5	83.3	2.5	83.5	5.1	112.8	5.1	113.4
APR	1.7	100.0	1.7	100.0	4.4	111.8	4.4	111.2
MAY	2.8	108.3	2.8	108.3	3.7	110.0	3.7	111.0
JUN	3.3	82.1	3.3	82.9	3.3	109.0	3.4	108.8
JUL	2.9	80.8	2.9	80.3	3.4	106.7	3.4	107.3
AUG	3.8	85.2	3.8	86.0	4.2	95.9	4.2	96.0
SEP	2.4	116.7	2.4	116.5	5.0	84.1	5.0	86.0
OCT	2.9	106.3	2.9	106.1	5.2	89.9	5.3	91.4
NOV	6.3	104.5	6.3	105.4	5.5	92.7	5.5	108.5
DEC	2.5	108.3	2.5	108.3	5.8	109.1	5.9	110.3
MEAN	3.2	102.7	3.2	102.7	4.7	104.0	4.8	105.8

of comparison, representing runoff under the current climatic condition. The period was used because it included the most recent cycle of high and low water levels.

(2) GFDL - The GFDL scenario represents the situation under $2XCO_2$ climatic warming as predicted by the GFDL model. The GFDL climatic change factors from Table 1 were used to modify the historical daily hydrometeorological data. The resulting data were used by the LBRM to generate the $2XCO_2$ GFDL basin runoff.

(3) GISS - Basin runoff for this scenario was determined as in the last case. The only difference was that the GISS climatic change factors were used instead of the GFDL factors.

Net Basin Supply Modelling

Apart from basin runoff, another important source of water supply for the Great Lakes is precipitation over the lakes. The large surface area of the lakes also implies that a large qunatity of water is lost thgrough evaporation from the lakes. The net basin supply (NBS) is the amount of water that a lake receives after basin runoff (R), over lake precipitation (P), and evaporation from the lake (E) have been taken into consideration. The relationship between these parameters can be expressed in the following equation:

$$NBS = R + P - E$$

The precipitation data compiled by the GLERL were chosen for use in the present study. For each of the Great Lakes, daily overlake precipitation (for the period January 1, 1956 to December 31, 1983) were first converted into equivalent depth of water in mm over the lake. The data were used as the Basis of Comparison (BOC), representing precipitation on the Great Lakes under the current climatic coditions. Changes in overlake precipitation under the $2XCO_2$ climatic warming scenarios as predicted by the GFDL and GISS models were computed simply by multiplying the BOC data by the GFDL and GISS monthly overlake precipitation change factors given in Table 1.

Overlake evaporation is an important component of net basin supply calculation for the Great Lakes because it constitutes a major loss of water from the lakes. Using the mass transfer technique, scientists at the Canadian Climate Centre computed evaporation from the Great Lakes under the current and future climatic conditions. When applying the GFDL and GISS scenarios to the lake evaporation model, it was assumed that lake temperatures and dew point temperatures would increase by the same amount as the projected air temperature increases (Cohen, 1986). The lake evaporation data produced by the Canadian Climate Centre were suitable for direct use in this study because the climate change scenarios were consistent in both studies.

Computation of the net basin supply for all the Great Lakes could be completed at this stage because data sets for basin runoff, overlake precipitation and overlake evaporation under each of the three climate scenarios (BOC, GFDL, and GISS) have been assembled. The overall effect of climatic change on Great Lakes net basin supply can be summarized by expressing the net basin supply for scenarios GFDL and GISS as a percentage of BOC net basin supply. The results of this comparison are summarized below.

	BOC	GFDL	GISS
Lake Superior	100	86.6	78.3
Lake Michigan	100	80.6	62.2
Lake Huron	100	82.6	69.5
Lake St. Clair	100	82.5	68.6
Lake Erie	100	75.4	61.1
Lake Ontario	100	88.0	67.5
Average	100	82.6	67.9

The overall reduction in net basin supply of the Great Lakes due to a $2XCO_2$ climate warming was 17.4% for scenario GFDL and 32.1% for scenario GISS. The greater reduction in net basin supply for scenario GISS is because the GISS model predicted a more substantial increase in temperature than the GFDL model. Under a warmer climate, more water will be lost to the atmosphere from the basin through evaporation and transpiration. If the net basin supply can be reduced by as much as 20 to 30%, the immediate question is whether a significant reduction in Great Lakes water levels would occur.

Great Lakes Water Levels Modelling

The model used in this study to calculate lake level changes under the BOC, GFDL and GISS scenarios was first developed by the United States Army Corps of Engineers, Detroit District. The computer program for the model is known as P4827. Development of the model was prompted by the 1977 Governments' Reference to the International Joint Commission. Program P4827 is a very large program containing hundreds of variables. Detailed description of the program is available (IGLDCUSB, 1981; ILERSB, 1981; ILERSB, 1984). There are three basic procedures used in the program to calculate the flow of water in the Great Lakes system, from Lake Superior to the St. Lawrence River. The first procedure models the existing regulatory control on Lake Superior by Regulation Plan 1977. The second procedure routes the water supplies and outflows through the middle lakes using the 1962 to 1968 conditions on the St. Clair and Detroit Rivers and the 1953 conditions on the Niagara River. The third procedure models the existing regulatory control on Lake Ontario by Regulation 1958D.

Circulation of the programs was limited because the software package was developed for inhouse use on main frame computer. In 1983, the University of Wisconsin-Madison Sea Grant Institute initiated a three-year study of Great Lakes water resource management (Loucks, 1985). The primary objective of the research was the development of policy analysis tools and a framework to aid in making decisions should the demand for competing uses of Great Lakes water increase in the future. It was determined that the best approach to developing a tool for assessing diversion impacts would be to adapt the Great Lakes Regulation Model and the associated impacts analysis models to potential future diversion situations. Through the efforts of the Wisconsin Sea Grant Institute researchers, the main frame programs were downloaded and implemented in the micro-computer environment. This was an important accomplishment because the programs have become much more transportable. For this reason, the micro-computer version of the Great Lakes Regulation Model (which was named Great Lakes Hydrologic Response Model by the Wisconsin Sea Grant Institute researchers) was selected over the main frame version for use in the present study.

The NBS data file available for use as input to the Great Lakes Hydrological Response Model (GLHRM) consisted of historical water supply data for the Great Lakes from 1900 to 1978. The data file was prepared by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. It was designated in the present study as the basis of comparison (BOC). In order to produce similar data files for the $2XCO_2$ GFDL and GISS climate change scenarios, monthly NBS conversion factors were developed. Each conversion factor represents the numerical difference in NBS between the BOC scenario and the GFDL or GISS scenario for the month. These factors were then superimposed upon the original NBS data file to derive NBS data file for each of the two climatic change scenarios.

The three NBS data files were used in turn as input to the GLHRM to produce outflows and levels for the Great Lakes under each of the BOC, GFDL and GISS climate scenarios. Only the summary results for Lake Erie will be presented here. As shown in Figure 2, the average reduction in Lake Erie water levels under the GFDL and GISS scenarios would be about 40 and 70 cm respectively. Because the possible reduction in Great Lakes water supply due to climatic warming could be

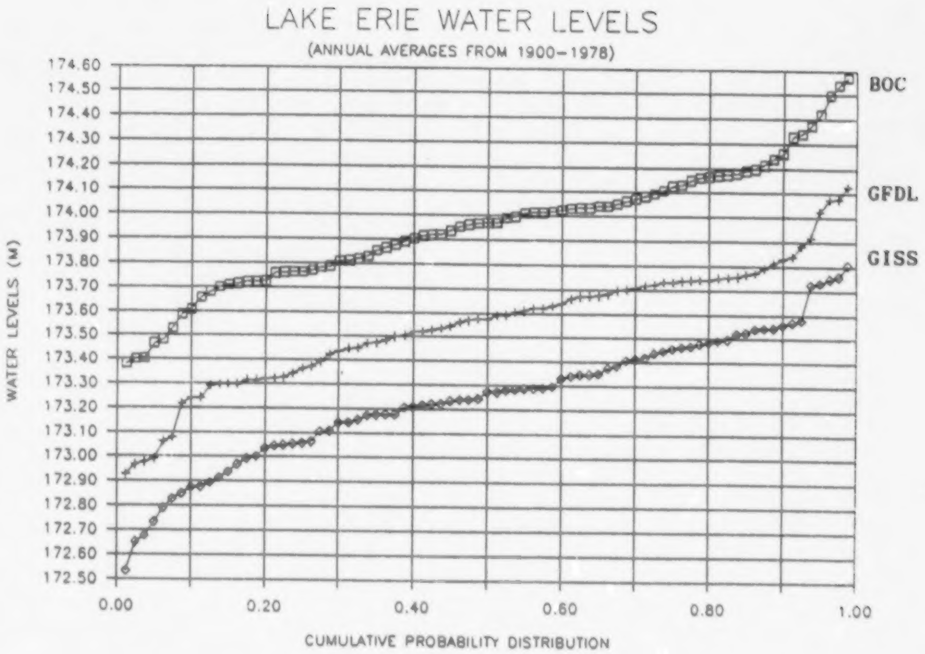
LAKE ERIE WATER LEVELS
(ANNUAL AVERAGES FROM 1900–1978)
WATER LEVELS (M)
174.60
174.50
174.40
174.30
174.20
174.10
174.00
173.90
173.80
173.70
173.60
173.50
173.40
173.30
173.20
173.10
173.00
172.90
172.80
172.70
172.60
172.50
0.00
0.20
0.40
0.60
0.80
1.00
CUMULATIVE PROBABILITY DISTRIBUTION
BOC
GFDL
GISS

Figure 2

quite large as shown by the modelling results, study is needed to explore measures, including emissions control of greehouse gases, water pricing, lake regulation, and interbasin diversion of water, to alleviate the potential low water levels problem.

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SESSION C

INTERBASIN TRANSFER OF WATER:

QUANTITY MODIFICATIONS

Moderator: Dr. L. Lau

National Water Research Institute
Burlington, Ontario

Effects of flow diversion on the runoff regimes of northern Ontario rivers

Ming-ko Woo[1] and Peter R. Waylen[2]

ABSTRACT

Three river systems in northern Ontario have been regulated for inter-basin transfer of water. The flow regimes of the exporting and the importing rivers were compared to the natural flow patterns of their neighbouring rivers. Diversion alters the annual flows and redistributes the monthly discharges. The long-term probability distributions of annual runoff, annual floods and annual low flows are also seriously affected. The Albany-English river systems are particularly interesting because they offer streamflow records for the periods before and after interbasin water transfer, making it possible to analyse the changes in their flow characteristics through time.

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INTRODUCTION

Where rivers are regulated, with or without flow diversion, the flow pattern is expected to be modified. With diversion, there is also a loss or gain in runoff that affects both the short-term and the long-term hydrological behaviour of the affected streams. The extent to which the flows are affected depends upon the flow regulation policy. Very often, little information is available on these policies which may themselves change as water demands are redefined. Day to day retention or release of water is based upon information concerning present situations (eg. water level in the reservoirs and current demands) and anticipated future conditions (eg. forecasted rates of inflow from upstream). It is therefore difficult in retrospect to explain observed fluctuations as anticipated causes do no always materialize. The result is a highly complex set of changes in streamflow; which can be generalized only in probabilistic terms.

In the natural state, flow conditions vary considerably from season to season and from year to year. The extent of these variations are reflected in the probability structure of the discharge. When the flow is regulated, the probability distribution is altered, and the effects of the river control measures are detectable only when the natural variability has been isolated. It is therefore necessary to compare the flow patterns of the regulated and their adjacent non-regulated streams.

In Canada, there are over 50 projects which transfer water from one drainage basin to another (Quinn 1983). For this study, examples are drawn from Western Ontario where three river systems that used to enter James Bay have been linked to the Great lake and Nelson River drainage for interbasin transfer. The ecological and land use planning impacts of two of these projects have been discussed by Day et al. (1982). The impacts of diversion upon other drainage basins in Canada were discussed by Rosenberg et al. (1987). These impacts often reflect the results of long-term changes in the hydrological environment rather than being merely the responses to isolated, brief events (such as individual floods). It is the purpose of this paper to analyse the ways in which diversion has altered several of the long-term discharge characteristics, including mean annual flows, annual floods and annual low flows. These three variables were chosen because they are measures that bracket the streamflow extremes and because they are commonly incorporated in hydraulic designs and in environmental planning.

STUDY AREA

The three western Ontario rivers that have undergone diversion are located in the Canadian shield where the rolling landscape is occupied by many lakes and wetlands. Annual precipitation increases eastward from 600 mm to 800 mm, about one-quarter of which falls as snow (Hutton and Black 1985). The cold winters cause the lakes and rivers to freeze, and prevent the snow from thawing until late April or May, when high flow is often associated with spring melt. High flow may also be produced by summer and autumn rainfall (Woo and Waylen 1984) but summer evaporation can reduce the flow.

The low divides between drainage basins facilitate interbasin transfer of water while the abundance of lakes provide natural reservoirs for water storage. The three diverted rivers are located at the headwaters of Albany River which empties into James Bay (Fig. 1). Water from the Kenogami, dammed in 1939, can be transferred through Long Lake to Lake Superior for hydro-power production. In 1943, the Ogoki River was dammed at Waboose Falls so that its water can be diverted to Lake Superior through Lake Nipigon. To the west, the upper Albany was dammed at the western outlet of Lake St. Joseph. There, flow has been released from the western end of Lake St. Joseph at Root Portage since 1958, to join the English River that enters the Nelson River in Manitoba, ultimately to research Hudson Bay. This flow diversion provides water to English River for power production, and to control the water level of the Lake of the Woods. English River itself has been regulated since 1929, and today the flow at Ear Falls is also fed by the Upper Albany basin.

EXAMPLES OF FLOW DIVERSION

To illustrate the changes in daily streamflow due to interbasin water transfer,the 1974 hydrographs for the affected rivers and their neighbouring unregulated streams are given in figure 2. At the western most location where water was diverted from the Albany, the natural flow pattern (as revealed by English River at Sioux Lookout) was late-winter low flow, followed by a late spring snowmelt peak that was slightly delayed by the storage effect of lakes (Ontario Ministry of the Environment 1978). The diversion of Lake St. Joseph at Root Portage was to deprive the upper Albany of water flow, to maintain a moderate level of runoff at English River at Ear Falls. This diversion was stopped during most part of summer because the natural basin of upper English River provided much of the discharge except during a brief period in August. At the Ogoki River system, the natural flow exhibited by the station above Whiteclay Lake was similar to that of the upper English River, but without the lake effect to delay the spring flood. The diversion operation again called for the release of winter and autumn flow to the Lake Nipigon channel, leaving the spring and summer flows to discharge through the lower Ogoki to reach James Bay. At the Kenogami-Long Lake area, a moderate level of low to Lake Superior was released from Long Lake at the expense of the Kenogami River, allowing only periodic releases of spring and summer discharge to the produce a spiky hydrograph for the Kenogami. The natural flow of the area, represented by the hydrograph of Little Current River north of the Kenogami, was similar to that of the Ogoki above Whiteclay Lake.

The 1974 example was not as drastic as in many years when the entire flow of the exporting rivers could be transferred out of their basins.

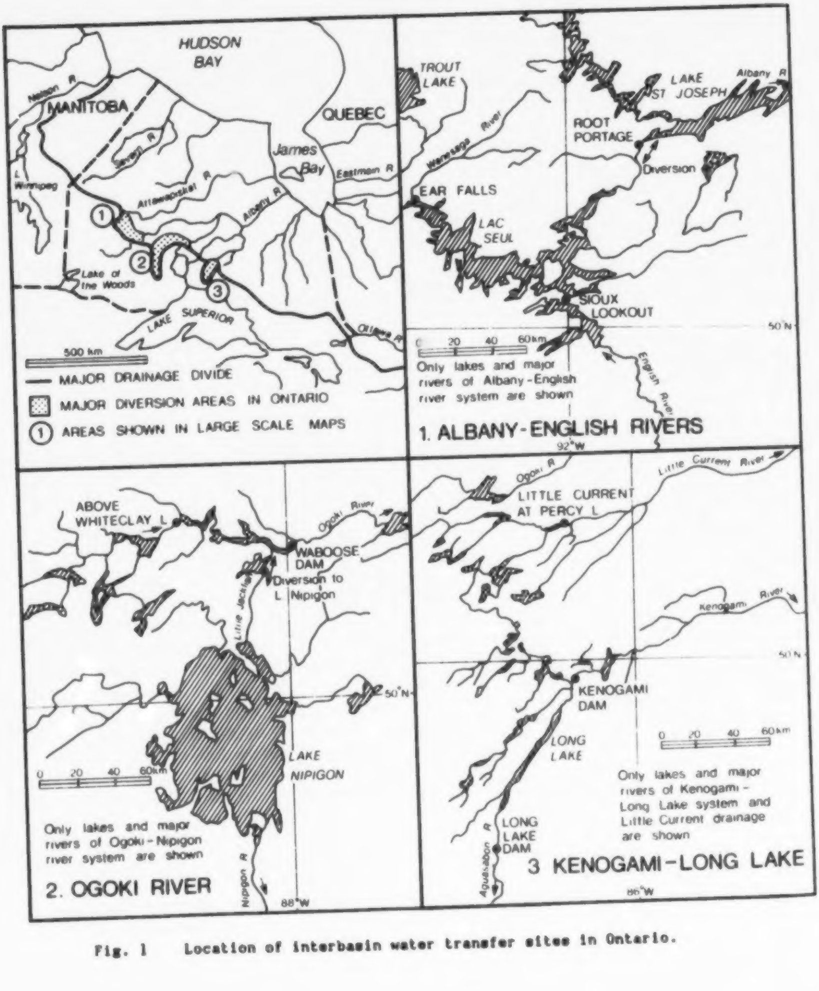
HUDSON BAY
MANITOBA
QUEBEC
James Bay
Nelson R
Severn R
Attawapiskat R
Albany R
Eastman R
L Winnipeg
Lake of the Woods
LAKE SUPERIOR
Ottawa R
500 km
MAJOR DRAINAGE DIVIDE
MAJOR DIVERSION AREAS IN ONTARIO
① AREAS SHOWN IN LARGE SCALE MAPS
TROUT LAKE
LAKE ST JOSEPH
Albany R
ROOT PORTAGE
Diversion
Wenasaga River
EAR FALLS
LAC SEUL
SIOUX LOOKOUT
50°N
0 20 40 60km
Only lakes and major rivers of Albany-English river system are shown
English River
1. ALBANY-ENGLISH RIVERS
92°W
ABOVE WHITECLAY L
Ogoki River
WABOOSE DAM
Diversion to L Nipigon
Little Jackfish
50°N
LAKE NIPIGON
0 20 40 60km
Only lakes and major rivers of Ogoki-Nipigon river system are shown
Nipigon R
88°W
2. OGOKI RIVER
Ogoki R
Little Current River
LITTLE CURRENT AT PERCY L
Kenogami River
50°N
KENOGAMI DAM
LONG LAKE
0 20 40 60km
Only lakes and major rivers of Kenogami-Long Lake system and Little Current drainage are shown
LONG LAKE DAM
Aguasabon R
3 KENOGAMI-LONG LAKE
86°W

Fig. 1 Location of interbasin water transfer sites in Ontario.

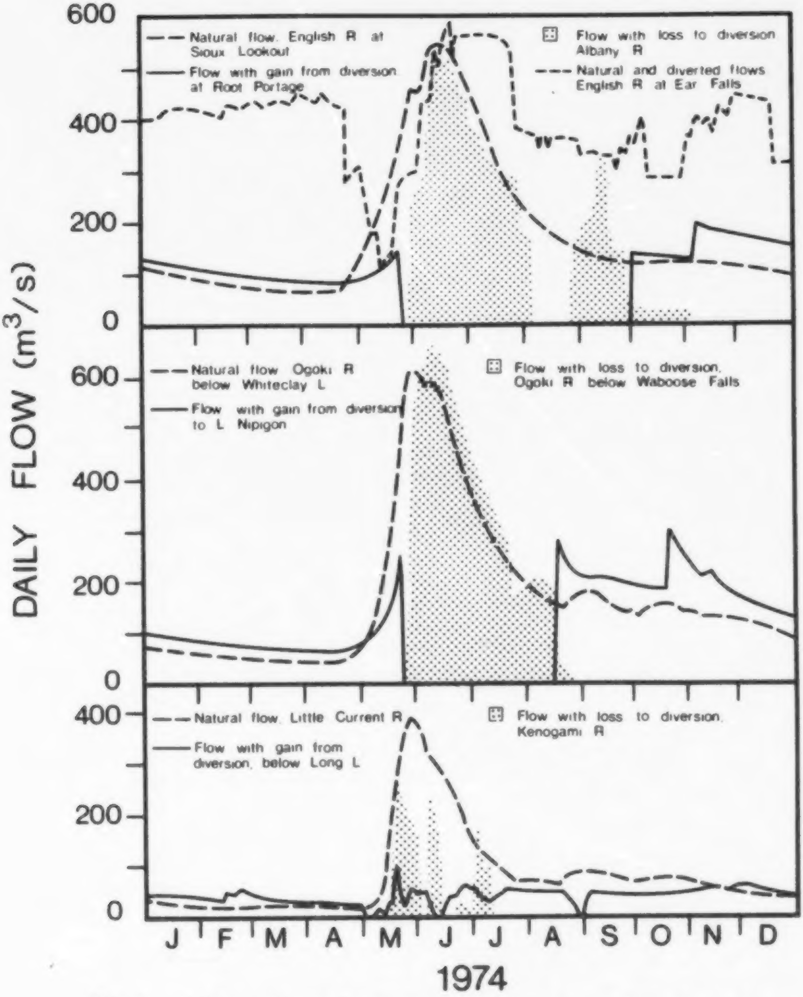

Fig. 2 **Daily hydrographs of rivers exporting and importing water compared with natural flow.**

CHANGES IN FLOW REGIME

The streamflow regime, or the average seasonal pattern of flow, is greatly disturbed by the demands of the diversion operation, mostly to provide a more even rate of discharge to the importing basins. Extending the 1974 daily discharge example, to include the monthly flows of 1972-76, figure 3 compares the flow from the natural and the diverted channels. For the Albany-English Rivers, all the flows of upper Albany was sent to the English River during moderate to dry years, but was let off the Albany on such wet years as 1974. The result was that the monthly flow of English River at Ear Falls seldom fell below 100 m^3/s, but the monthly high flows were kept below 500 m^3/s. Diversion operation at Ogoki Lake was quite different in that almost all the flows were exported to Lake Nipigon, except in the years of exceptionally high discharge, such as 1974. The diverted outflow was therefore similar to the natural flow pattern, while the original channel from which water was exported received little water during most times of the year. The Kenogami was operated differently again, with its flow diverted to Long Lake at a more uniform rate, and most of the peaks were directed back to the original Kenogami channel. Thus, the diversion measure in the three cases were different, and the resulting monthly hydrographs were quite dissimilar.

MEAN ANNUAL FLOWS

The mean annual flow, defined as the discharge averaged over 365 calendar days of a year, will be strongly affected by flow diversion because of water losses from the basins of James Bay drainage, and annual gains by the importing basins. The mean annual flows of the affected rivers are plotted on probability graphs (Fig. 4). A comparison of the probability distributions of the flows from different stream summarizes the manner in which the long-term fluctuations in annual discharge is altered by the regulation procedures.

For all the three rivers Albany, Ogoki below Waboose Falls, and Kenogami, there was a high probability that the mean annual flow is zero or negligibly small because they export the bulk of their water during low to moderate runoff years. On years of high flow, a substantial portion of their runoff is allowed to pass back to the natural channels and therefore there is a limited probability that these rivers experience flows at least as high as the long-term average annual flows of the importing rivers. To the rivers that receive the diverted flow, the year to year changes in annual discharge (i.e. the coefficient of variation of the long-term annual discharge) was maintained at about 25 percent even though the long-term means of the three rivers range from 39 m^3/s at Long Lake outflow, 75 m^3/s at Root Portage for Lake St. Joseph outflow, and 112 m^3/s at Ogoki outflow to Lake Nipigon (Table 1). The probability distribution of mean annual flows of these three drainage systems are different. The Ogoki loses most of its water to lake Nipigon, and the importing river shows a probability distribution similar to that of the natural flow above Whiteclay Lake. At the Kenogami-Long Lake area, high flows are often

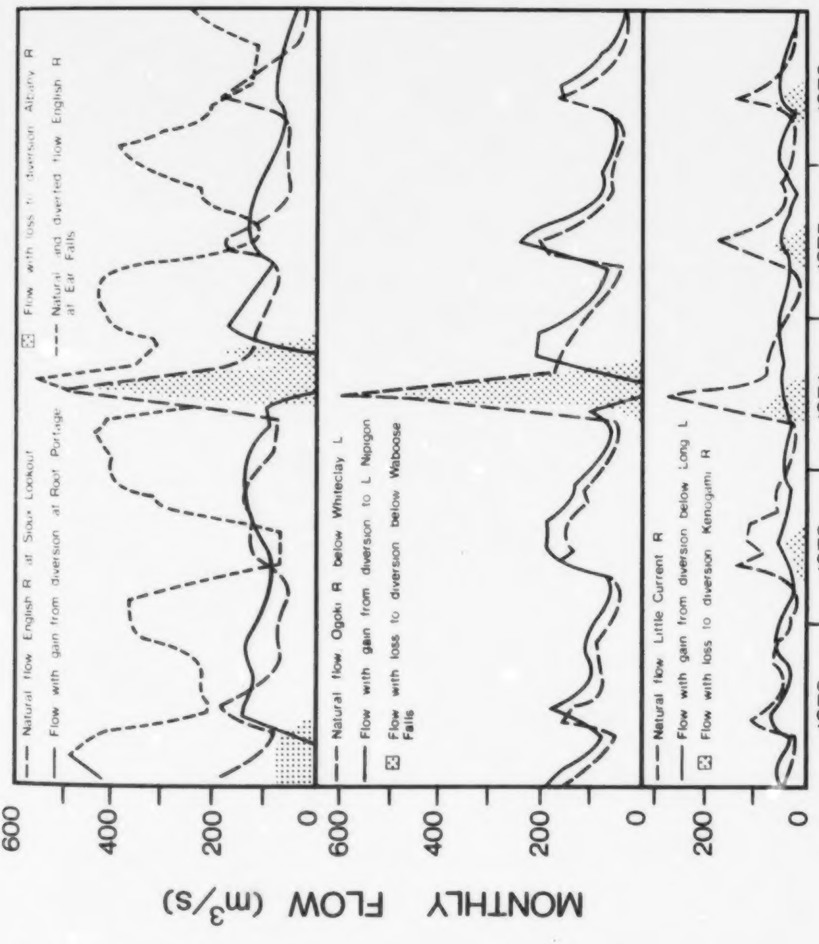

Fig. 3 Monthly flows of rivers exporting and importing water compared with natural flow.

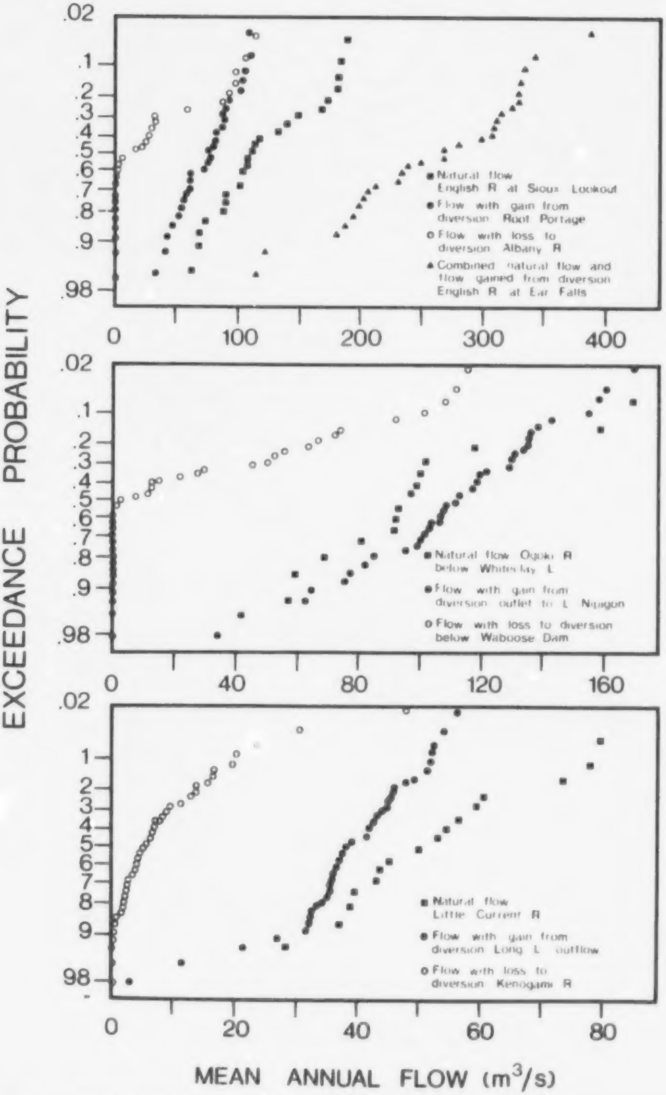

Fig. 4 Probability distributions of mean annual flows of rivers affected by interbasin transfer, compared with natural flow (plotted on probability graph papers).

Table 1 **Long term statistics for several streamflow characteristics of basins affected and unaffected by flow diversion.**

Period		**Mean Annual Flow**		**Annual Flood**		**Annual Low Flow**	
		Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Outlet to Albany R.	1936-57	87.1	22.7	274.3	74.0	33.4	15.9
	1958-85	30.0	38.9	143.0	171.8	0.3	0.5
Outlet at Root Portage	1958-85	74.9	21.3	149.8	38.3	14.5	24.8
English R. at Ear Falls	1907-28	197.5	45.4	289.1	105.2	111.7	25.1
	1929-57	180.1	49.9	378.1	187.3	60.8	32.2
	1958-85	261.5	68.8	464.6	128.2	65.4	44.8
English R. at Sioux Lookout	1928-57	132.7	33.2	337.0	142.1	47.6	14.0
	1958-81	121.6	40.2	279.6	114.2	49.6	14.8
Kenogami R.	1939-85	8.1	9.0	169.3	92.5	0.05	0.2
Long L. Outflow	1939-85	39.2	9.9	89.1	16.4	2.4	5.8
Little Current R.	1969-85	52.8	14.6	180.7	71.3	12.8	2.9
Ogoki below Waboose Falls	1943-85	24.7	35.3	225.2	312.4	0.04	0.3
Outflow to L. Nipigon	1943-85	112.2	29.3	277.8	83.3	27.8	26.0
Ogoki below Whiteclay L.	1972-85	100.0	31.2	252.4	126.5	39.9	8.3

allowed to pass through the Kenogami so that the Nipigon diversion does not receive the full supply of natural flow each year. Consequently, it has a high probability of low annual flows and low probability of high annual flows compared with the natural flow pattern (such as Little Current River). The English River receives not only the natural flow from its upper basin (see the graph for Sioux Lookout) but also imports water from the Albany via Root Portage. Thus, at Ear Falls,the English River has a large volume of flow (long-term mean was 262 m^3/s compared with 122 at Sioux Lookout and 75 at Root Portage). It also has a large range of annual flows (standard deviation was 69 m^3/s compared with 40 at Sioux Lookout and 21 at Root Portage), but relative to its long-term mean, the coefficient of variation was only 25 percent which is smaller than that of the natural flow at Sioux Lookout (33 percent).

The Albany-English river example is particularly useful in illustrating the hydrological changes before and after diversion because some records dated back to 1907 (Fig. 5). The English River at Ear Falls, had natural flow up to 1928 and then it was regulated for hydro-power generation. After 1958, it received water diverted from the Albany drainage. The annual flows, averaged between 1907-1928 and 1929-1957 were not statistically different (198 vs 180 m^3/s) and their standard deviations were also similar (45 vs 50 m^3/s), suggesting that regulation of flow alone may not significantly alter the mean annual flows. Since 1958, however, there was a substantial flow increase, accompanied by a larger variance in flow. That this is attributed to flow diversion effect, is proven by a comparison with the discharge at Sioux Lookout which has been recording natural flow since 1921. The mean flow at Sioux Lookout averaged 133 m^3/s between 1928-57, and 122 m^3/s between 1958-81 while the standard deviations were 33 and 40 m^3/s for these periods. The higher value at Ear Falls must therefore be attributed to the increases in flow as well as to the larger variation of flow after diversion. These features are also revealed on the probability distribution plots (Fig. 6). On the other hand, while an average of 75 m^3/s was diverted to the English River drainage through Root Portage, the Albany suffered a decrease in flow. The pre-diversion annual discharge to Albany River, averaged between 1936 and 1957 was 87 m^3/s with a standard deviation of 23 m^3/s. Afterwards, annual flow averaged 30 m^3/s but the standard deviation rose to 39 m^3/s. Diversion, in this case, has increased the year to year variations in flow to both the basins that provides and the one that receives water supplies.

ANNUAL FLOODS

Annual floods, being the highest flows of each year, can be described by the Gumbel distribution if they are generated by natural processes such as snowmelt or rainfall (Waylen and Woo 1982). The probability distribution of annual floods for various stations are plotted on Gumbel papers as shown in figure 7.

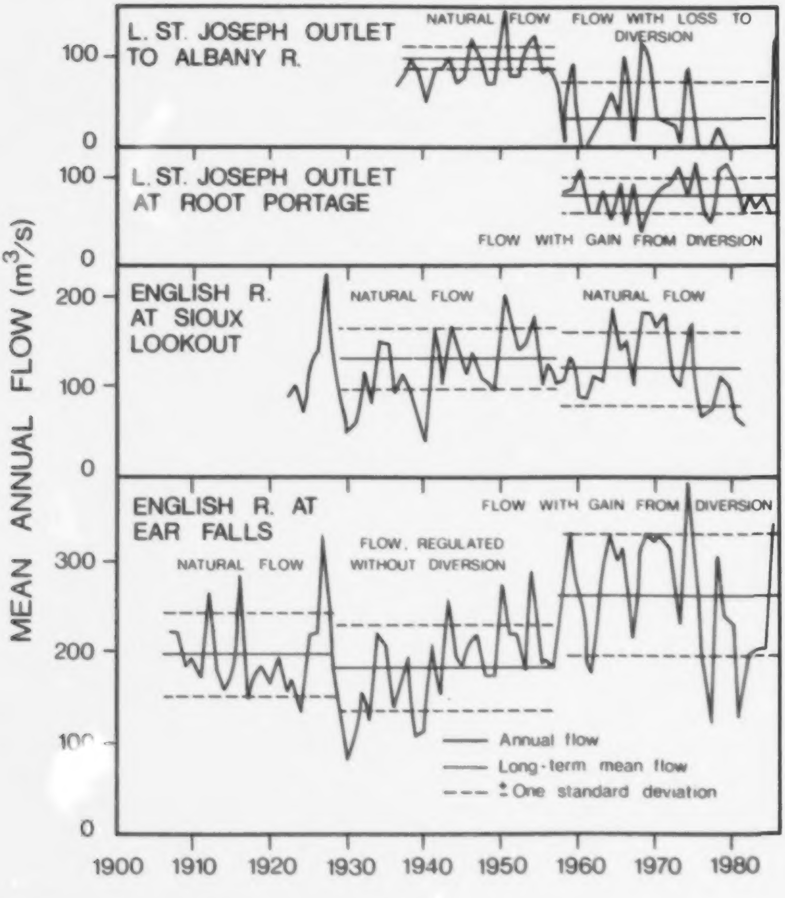

Fig. 5 Mean annual flows of the Albany-English river system before and after diversion.

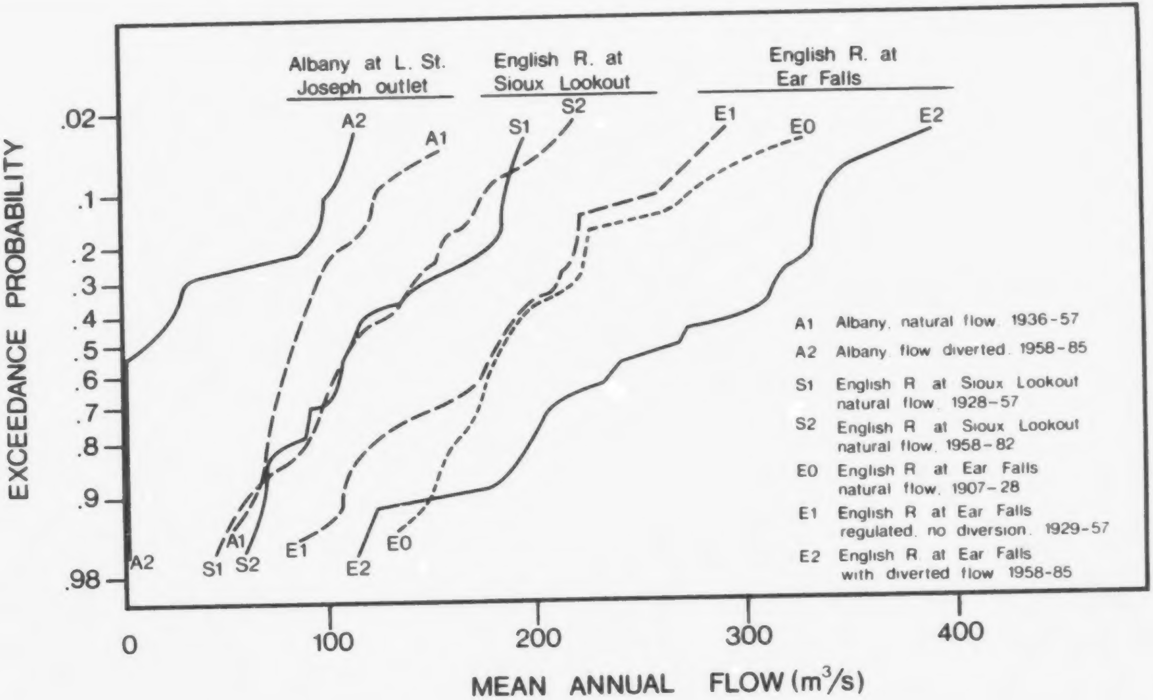

Fig. 6 Changes in probability distributions of annual flows after diversion, Albany-English river system (plotted on probability graph paper).

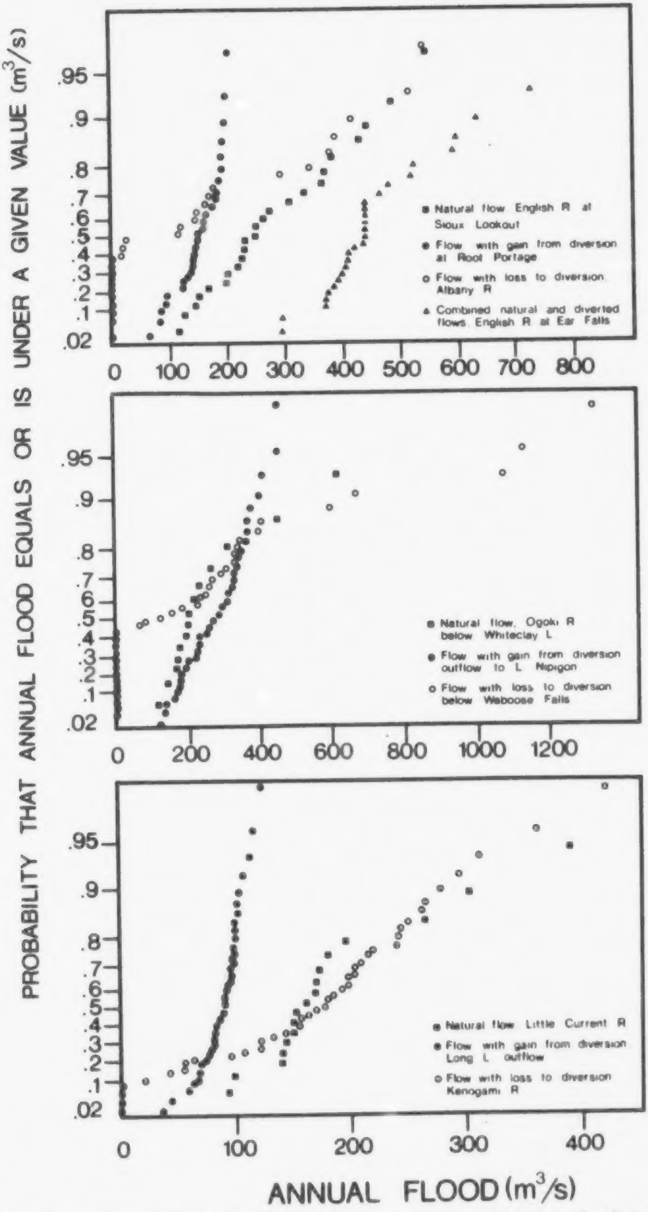

Fig. 7 Probability distributions of annual floods of rives affected by interbasin transfer, compared with natural flow (plotted on Gumbel papers).

All three importing basins have a small range in annual floods, relative to the natural rivers, with a coefficient of variation for the entire diverted period being 30 percent or under. This is due to the operation that very high flows were sent back to the original channels. Thus, the original flow channels still convey the very high floods during the wet years, but in the drier years, the flood flow and indeed the entire flow of the year, is exported. The net result is that the annual floods are highly variable, sometimes being zero, and at other times much higher than the flows in the receiving channels.

The Albany-English system again permits a comparison of annual flood behaviour before and after diversion (Fig. 8). The natural flow of English River at Sioux Lookout provides a reference against which man-made changes can be deduced. The period 1929-57 yielded slightly larger average annual floods than between 1958-85 because of the occurrence of several very high runoff events. At Ear Falls, however, the reverse occurred. The standard deviations for the second period was slightly lower at Sioux Lookout, but was greatly reduced at Ear Falls. The latter contrasts sharply with upper Albany where the mean annual floods dropped greatly after diversion, but where the standard deviation of floods doubled that of the pre-diversion period. This example confirms that diversion has led to a reduction of the year to year floods for the receiving channel, but the reverse is achieved for the exporting rivers.

ANNUAL LOW FLOWS

Annual low flow is the lowest discharge during a calendar year. Unregulated rivers in western Ontario that drain basins with sizes comparable to those of the Ogoki, Kenogami or upper Albany seldom have zero flow (Ontario Ministry of the Environment 1979). When affected by interbasin transfer, the probability distribution of the annual low flows are altered.

Flow records are available for the Albany-English river system to cover the periods before and after the diversion. The English River at Sioux Lookout has not been influenced by diversion. The probability distribution of its annual low flows remained similar for both periods, suggesting that there was little environmental change that would alter the annual low flows. The upper Albany had natural flow before 1958 and at that time, it seldom had a zero low flow. After 1958, the probability of zero flow was 0.6, and this was due to the need to withdraw all its water during at least part of each year to feed the English River. On the receiving side, at Root Portage, zero low flows were also recorded, but the coefficient of variation of its annual low flows was also very high (170 percent vs 30 percent for English River at Sioux Lookout). These features of minimal annual low flows in the supplying basin and a highly variable annual low in the receiving basin are also witnessed in the Ogoki and the Kenogami drainages.

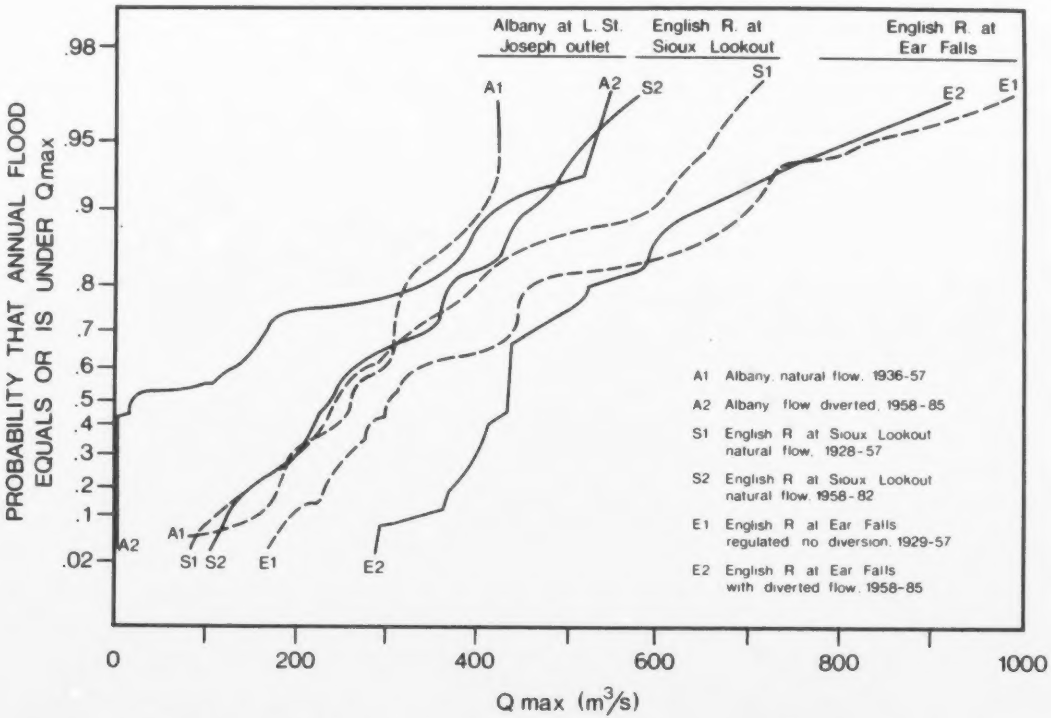

Fig. 8 Changes in probability distributions of annual floods after diversion, English-Albany river system (plotted on Gumbel paper).

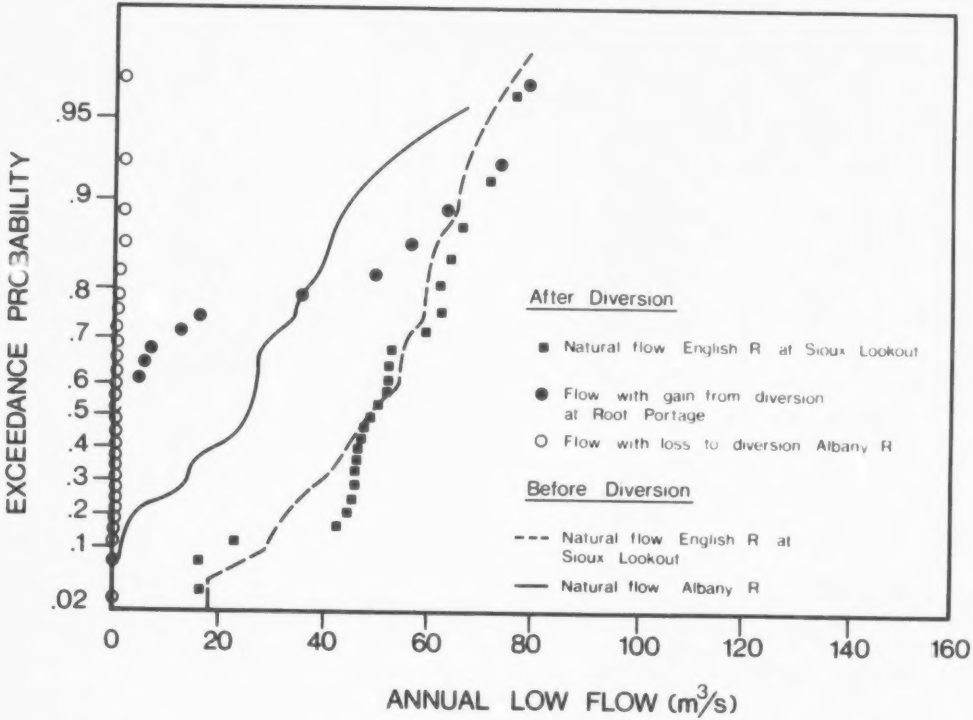

Fig. 9 Probability distributions of annual low flows for rivers of the Albany-English river system (plotted on Gumbel paper).

CONCLUSION

It is difficult to account for the day to day alteration of streamflow for rivers experiencing interbasin water transfer because of the complexity of their natural flows and the uncertainty in the actual diversion operation. When the flow data are aggregated over an extended period, however, the pattern of changes can be generalized through the probability structure of several flow characteristics of the rivers thus affected.

Rivers that export water invariably undergo losses of flow and the statistical distribution of their annual flows shows a high probability of zero or very low flows. Peak runoff for these rivers becomes more variable from year to year because very high floods are still permitted to pass through the original channels but the lower floods may be released to the importing channels. In terms of annual low flows, the exporting basins are often responsible for maintaining a guaranteed minimum discharge to the importing basins, and therefore there is a high probability of zero or extremely low annual low flows for the exporting basins.

While the long term mean flow for the importing basins are increased, their coefficients of variations are kept at around 25 percent. This is to maintain a steadier level of water supply from year to year. One other consequence is that the range of annual floods is also reduced, with long term coefficients of variation of about 30 percent. Annul low flows, however, are more variable, with coefficients of variation exceeding 100 percent. Zero flow also occurs though the probability of its occurrence is lower than that for the exporting rivers.

This paper has only examined the long-term variations in three major streamflow characteristics due to interbasin water transfer, but definite hydrological trends can be recognized. An identification and quantification of the changes in the streamflow regime will lead to better understanding and prediction of the nature and extent of the impacts of river regulation upon the hydrological environment.

ACKNOWLEDGEMENTS

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Impact of Interbasin Transfers
on
Lake Diefenbaker Operation

by

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E. Light, P. Eng.; D. Euteneier, P. Eng.

ABSTRACT

The Saskatchewan River system comprises the single most reliable water source in southern Saskatchewan. A major step in managing this vital resource was the construction of Gardiner Dam and the creation of Lake Diefenbaker during the 1960's.

The creation of Lake Diefenbaker sparked the imagination of the public and water managers alike. Various proposals have been made to divert water from Lake Diefenbaker to water-short areas outside the South Saskatchewan River basin. This paper analyzes the impact some of these interbasin transfer proposals would have on the operation of Lake Diefenbaker in terms of reservoir levels and flows downstream of Gardiner Dam.

BACKGROUND INFORMATION

Plans for damming the South Saskatchewan River persisted in one form or another for over 100 years. In 1958 a Canada-Saskatchewan agreement was signed to share the costs in creating a major reservoir (Lake Diefenbaker) on the South Saskatchewan River. Lake Diefenbaker was formed by the construction of Gardiner Dam on the South Saskatchewan River and the smaller Qu'Appelle River Dam at the upper end of the Qu'Appelle Valley. Lake Diefenbaker is 225 km long, has a surface area of 43,000 ha, a total storage of 9.4 million dam^3 and a usable storage of 4.0 million dam^3. The reservoir serves a number of purposes including municipal, domestic, industrial, power generation, irrigation, recreation, flood control, water fowl projects, maintenance of minimum flows and withdrawal location for interbasin diversion.

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The hydrologic characteristics of the basin are described as follows:

> The South Saskatchewan River above Gardiner Dam has a gross drainage area of 135,600 km^2 and an effective drainage area of 86,670 km^2. The main tributaries are the Red Deer, Bow, Oldman, St. Mary and Waterton Rivers. The eastern slopes of the Rocky Mountains contribute about 80 per cent of the average annual runoff while comprising only 20 per cent of the total drainage area. Generally, peak flows from the foothill and prairie runoff occur in April and May, followed by a higher peak flow runoff in June.
>
> The natural average annual inflow into Lake Diefenbaker for the 70 year period, 1912 to 1981, is 9.1 million dam^3. The natural annual inflow to the lake has ranged from a low in 1941 of 4.0 million dam^3 to a high in 1916 of 18.6 million dam^3.[1]

ISSUES RAISED BY INTERBASIN DIVERSION

Interbasin diversion of water out of any host basin raises a number of issues which need to be addressed. These issues for the South Saskatchewan River Basin include: apportionment requirements; changes in river regime; power production losses for existing and future hydroelectric stations; irrigation development both on the reservoir and downstream of Lake Diefenbaker; recreation; water quality; ferry operations; wildlife in the Saskatchewan River Delta; fisheries; relocations of water intakes; social-political-economic impact; and, biological.

Many of these issues also need to be addressed for the basin receiving the interbasin transfer of water.

WATER DIVERSION PROPOSALS

Many of the interbasin diversion schemes for Lake Diefenbaker received preliminary evaluation in the Saskatchewan-Nelson Basin Board (SSNB) study which took place in the late 1960's and early 1970's.[2] Since the time of the SSNB study some of these proposals have been modified and new proposals have been made. Table 1 lists these proposals along with their associated costs. The location of these proposal schemes are shown in Figure 1. A number of interbasin diversions have also been proposed in the past 20 years in the headwaters of the Saskatchewan River in Alberta. These proposals are not discussed in this paper even though they could have an effect on inflows into Lake Diefenbaker.

Table 1. INTERBASIN TRANSFERS ASSOCIATED WITH LAKE DIEFENBAKER

Diversion	Flow (m^3/s)	Volume ($1000\ dam^3$)	Time Period	Capital Cost Millions of $	Operation Cost Millions of $
Eaglehill[1]	142	2,233	April	211.5	18.3
(to Lake Diefenbaker)	283	4,450	to	282.5	32.6
	425	6,683	Sept.	345.5	46.8
Souris River[2]	10.6	138	May	37.3	1.6
	14.2	185	to	43.5	2.3
	28.3	369	Sept.	59.1	3.9
	42.5	554		73.2	5.4
Assiniboine River[1]	14.2	223	April	37.5	3.1
	70.8	1,113	to	87.5	8.3
			Sept.		
Qu'Appelle River[1]	14.2	223	April	21.5	1.4
	36.8	579	to	35.5	2.2
	70.8	1,113	Sept.	56.5	3.5
	1:50 flood	--		83.0	5.2
Regina-Moose Jaw[3]	Varying flow	115.8	Annual	11.0	.37
		422.2		15.0	.37
		582.0		132.0	4.0
Coronach Water Supply[4]	Varying flow	7.1	Annual	13.8	2.4
		45.0		79.6	10.0
		79.5		194.0	21.3
Upper Swift Current[5] and Wood River (5-phase project)	4.2 to 65.1	88 to 1,367	March to Oct.	No costs available though project is not economically feasible at present.	

[1] Reference 2
[2] Reference 3
[3] Reference 4
[4] Reference 6
[5] Reference 5

The following is a brief description of the diversion proposals associated with Lake Diefenbaker.

Eaglehill Diversion

The Eaglehill diversion was first investigated as part of the SSNB study. The diversion scheme was to transfer water from the proposed Callaghan Reservoir on the North Saskatchewan River to Lake Diefenbaker. The conveyance route was to be located in the general area of Eaglehill Creek. Since 1972, two other diversion schemes have been proposed which involve similar components. Any of these diversion schemes are unlikely to develop in the near future due to the high costs involved.

Souris River Diversion

The Souris River diversion was first proposed in the SSNB study and later investigated in greater detail during the Souris River Basin Study.[3] The most likely diversion route from Lake Diefenbaker would be down the Qu'Appelle River to near Craven and than overland to the Souris River near Weyburn. This diversion scheme was proposed in connection with the proposed Rafferty-Alameda projects as a means of realizing long-term future development potential in the Souris River Valley corridor.

Assiniboine River Diversion

The Assiniboine River diversion was also first investigated as part of the SSNB study. The conveyance route from Lake Diefenbaker would be down the Qu'Appelle River to near Craven and than overland to the headwaters of the Assiniboine River. The Kamsack reservoir on the Assiniboine River would be used for storing the diverted water.

Qu'Appelle River Conveyance

The Qu'Appelle River Conveyance was also investigated in the SSNB study. The project would provide an increased water supply and reduce flood damages along the Qu'Appelle River. The increased water supply would go to meeting future irrigation, municipal and industrial demands in the basin.

Regina - Moose Jaw Water Supply

A long-term water supply study for the Regina and Moose Jaw region was carried out by PFRA in 1980.[4] The study presented a variety of water supply alternatives, some of which involved transfer of water from Lake Diefenbaker. The most expensive alternative listed in Table 1 also included the transfer of water to the Souris River Basin.

Coronach Water Supply Diversion

The Coronach Water Supply Study was carried out by PFRA in 1977.[6] Diversion of water from Lake Diefenbaker was one of the components of the study. The conveyance route would be down the Qu'Appelle River to Buffalo Pound Lake and then overland to the East Poplar River.

Upper Swift Current Creek and Wood River

PFRA is in the process of carrying out a study on the diversion of water from Lake Diefenbaker to the upper region of Swift Current Creek and Wood River. Development would take place in five phases. Initial results indicate that none of the project phases are presently economical.

MODEL DEVELOPMENT AND SCENARIO TESTING

In May, 1986, the Canada-Saskatchewan South Saskatchewan River Basin Study Agreement was signed. The two parties to the agreement were Environment Canada and the Saskatchewan Water Corporation. The 1.6 million dollar study consists of developing a framework plan for water resources development in the basin, developing a methodology for project evaluation and implementation of study recommendations.

The Hydrology Service, Saskatchewan Water Corporation, was contracted to develop a water management model to evaluate existing and proposed development scenarios. The Water Resources Management Model (WRMM) developed by Alberta Environment was selected as the model for this purpose. The model was only recently made operational and the model runs made to evaluate the interbasin diversions considered herein represent only initial test results. Four scenarios were developed to model the impact of interbasin diversions on Lake Diefenbaker and downstream flows. The base case for this study assumes the existing 1986 level of development. This level of development already includes some interbasin diversion to the Qu'Appelle River basin. Each scenario assumed a 1986 level of development along with an additional interbasin diversion. The volumes, flows and time periods for each scenario are listed in Table 2.

Table 2. SCENARIO IDENTIFICATION FOR INTERBASIN DIVERSIONS

Scenario	Diversion	Flow		
1	Souris	10.6 m^3/s (375 cfs) from May 1 to October 31		
2	Souris	28.3 m^3/s (1000 cfs) from May 1 to October 31		
3*	Regina-Moose Jaw and Souris	Municipal:	Summer	3.043 m^3/s
			Winter	2.184 m^3/s
		Industrial:	Annual	3.622 m^3/s
		Recreation:	Summer	6.332 m^3/s
		Agriculture:	May to August	32.7 m^3/s
4	Regina-Moose Jaw and Souris and Qu'Appelle	Municipal, Industrial and Recreation same as Scenario 3		
		Agriculture:	May to August	113.3 m^3/s

* Summer: April to September
Winter: October to March

Scenarios 1 and 2 model interbasin diversion from Lake Diefenbaker to the Souris River for two levels of flows. These scenarios were identified during the Souris River Basin Study in connection with the proposed Rafferty-Alameda projects as means of realizing long-term future development potential in the Souris River basin. Scenario 3 models the diversion of water for the Regina - Moose Jaw region which also includes some diversion to the Souris River. The elements of this scenario were identified during the Regina-Moose Jaw Long Term Water Supply Study. Scenario 4 is the same as scenario 3 but with a higher irrigation demand. This higher irrigation demand was set since most interbasin diversion schemes require the majority of water for irrigation purposes.

MODELLING RESULTS

A number of plots were prepared to show the impact of interbasin diversions on Lake Diefenbaker elevations and downstream flows in the South Saskatchewan and Saskatchewan Rivers. Figures 2 to 5 show comparisons of Lake Diefenbaker end-of-month elevation for the base case versus scenarios 1 through 4. These plots show that the interbasin diversions considered only have a significant impact on reservoir levels during extended low flow periods. A measure of the impact is the number of years Lake Diefenbaker is lowered to the minimum drawdown level (MDL) of 545.590 m. In the base case Lake Diefenbaker reached the MDL in 1 month of 1 year. In scenarios 1 and 2, the MDL was obtained in 2 and 3 years, respectively. This represents a relatively minor impact on Lake Diefenbaker elevations compared to the base case (see Figures 2 and 3). However, in scenario 3, the MDL is achieved in 14 years or in 23.7 percent of the years simulated. This represents a significant impact on Lake Diefenbaker elevations relative to the base case (see Figure 4). Similarly, Lake Diefenbaker's MDL is reached in 22 years or 37.3 percent of the years simulated in scenario 4 (see Figure 5).

Figure 6 shows the difference in Lake Diefenbaker elevation between the base case and each of the four scenarios. Scenario 1 shows the least deviation from the base case with elevation differences always less that 1 metre. More significant departures from the base case are evident in scenarios 2 and 3, where elevation differences reach as much as 3 and 4 metres, respectively. Elevation differences were most pronounced in scenario 4 where the variation from the base case was consistently in the 2 to 4 metres range with several years over 5 metres and in two years over 6 metres.

Figures 7 to 10 show the reduction in flows at Saskatoon for the base case versus the four scenarios. The impact of the interbasin diversion on flows at Saskatoon can be evaluated using the frequency and magnitude of the mean monthly flow reduction relative to the base case. In scenario 1, there was flow reductions in 104 of the 708 months simulated compared to the base case or 14.7 percent of the months. The mean monthly flow reduction was usually less than 50 m^3/s with a maximum of 115.3 m^3/s. In scenario 2 a flow reduction occurred in 17.8 percent of the months with the decrease usually less than 100 m^3/s and a maximum of 213.0 m^3/s. There was a significant increase in the frequency of flow reduction in scenarios 3 and 4. The flow reduction frequency of scenario 3 increased to 39.7 percent of the months with decreases generally less than 140 m^3/s and a maximum of 233.9 m^3/s. Similarly, in scenario 4, the flow reduction frequency was 42.1 percent with flow decreases usually below 210 m^3/s and a maximum of 289.7 m^3/s.

Figure 11 shows the flow at the Saskatchewan-Manitoba boundary for scenario 4 and the required apportionment flow. This figure illustrates that the scenario with the largest increased water use did not violate the apportionment requirements to Manitoba.

Table 3 lists the average flow or elevation for various locations within the South Saskatchewan River basin for the base case and each scenario. Scenario 4 shows the most dramatic deviations from the base case with an average Lake Diefenbaker elevation decrease of over 2 metres, an average Saskatoon mean monthly flow decrease of 31 m^3/s or 23.9 percent and an average South Saskatchewan River Irrigation District (SSRID) and Saskatoon South East Water Supply (SSEWS) diversion reduction of 17,000 dam^3/year or 16.4 percent. Table 3 also shows that the average mean monthly flow in the Saskatchewan River at the Manitoba boundary was not significantly reduced under any of the scenarios.

Table 3. AVERAGE FLOW OR WATER LEVELS ASSOCIATED WITH INTERBASIN TRANSFERS FROM LAKE DIEFENBAKER

Location	Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Lake Diefenbaker Elevations (m)	551.25	551.04	550.59	550.29	549.22
South Saskatchewan R. at Saskatoon (m^3/s)	130	126	120	115	99
Saskatchewan River at Manitoba Boundary (m^3/s)	461	457	451	446	430
SSRID and SSEWS Diversion (dam^3/year)	104,000	104,000	101,000	100,000	87,000
Qu'Appelle Diversion (dam^3/year)	84,000	216,000	430,000	495,000	1,147,000

SUMMARY

Lake Diefenbaker will have only a limited supply of water available for interbasin diversion due to the many existing and proposed future demands on the reservoir and the need for meeting downstream flow requirements. All the diversion schemes listed in Table 1 cannot be supplied from Lake Diefenbaker even if the present restrictions on the operation of Lake Diefenbaker are removed.

A short-coming of the study results is that they are expressed in terms of average flow values and are the product of a water balance procedure with no real-time forecasting and reservoir operating decisions. In practice, many of the impacts on reservoir levels and downstream flows identified herein, particularly in scenario 1 and 2, could be alleviated through appropriate reservoir operating decisions.

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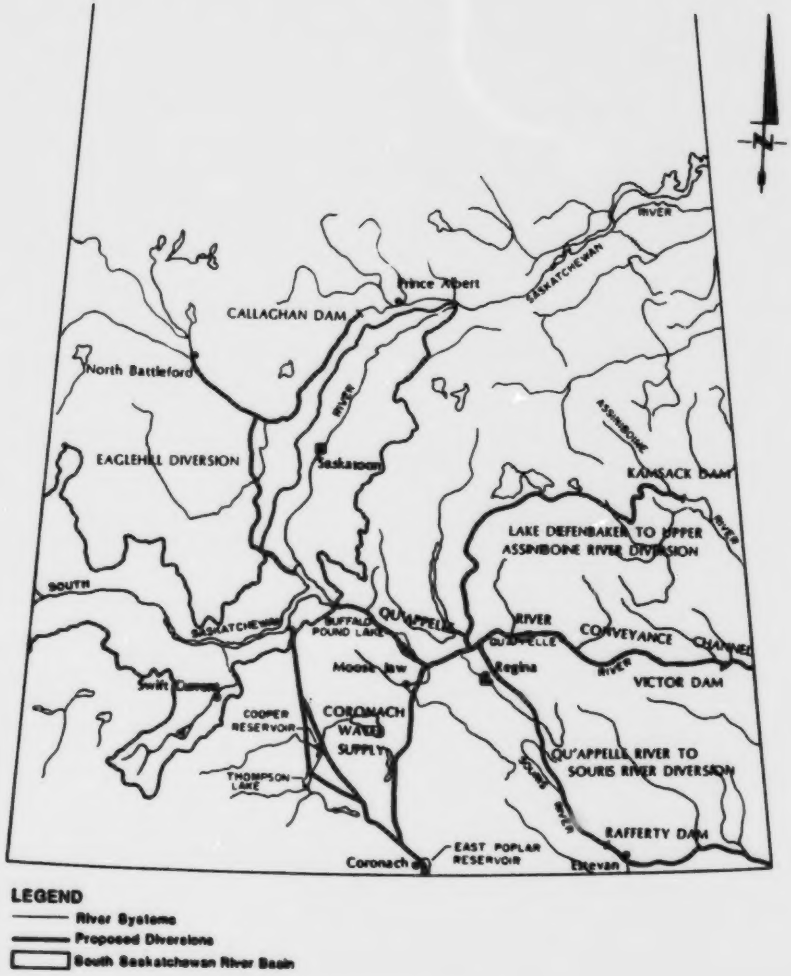
Prince Albert
CALLAGHAN DAM
North Battleford
RIVER
SASKATCHEWAN
RIVER
Saskatoon
EAGLEHILL DIVERSION
ASSINIBOINE
KAMSACK DAM
RIVER
LAKE DIEFENBAKER TO UPPER
ASSINIBOINE RIVER DIVERSION
SOUTH
SASKATCHEWAN
BUFFALO
POUND LAKE
QU'APPELLE
RIVER
QU'APPELLE
CONVEYANCE
CHANNEL
RIVER
Regina
Moose Jaw
VICTOR DAM
Swift Current
COOPER
RESERVOIR
CORONACH
WATER
SUPPLY
QU'APPELLE RIVER TO
SOURIS RIVER DIVERSION
THOMPSON
LAKE
SOURIS
RIVER
RAFFERTY DAM
Coronach
EAST POPLAR
RESERVOIR
Estevan
N
LEGEND
River Systems
Proposed Diversions
South Saskatchewan River Basin

FIG. 1 PROPOSED DIVERSION LOCATIONS

Source: Reference 7

LAKE DIEFENBAKER

1928 – 1986 RESERVOIR ELEVATIONS – SCENARIO 1

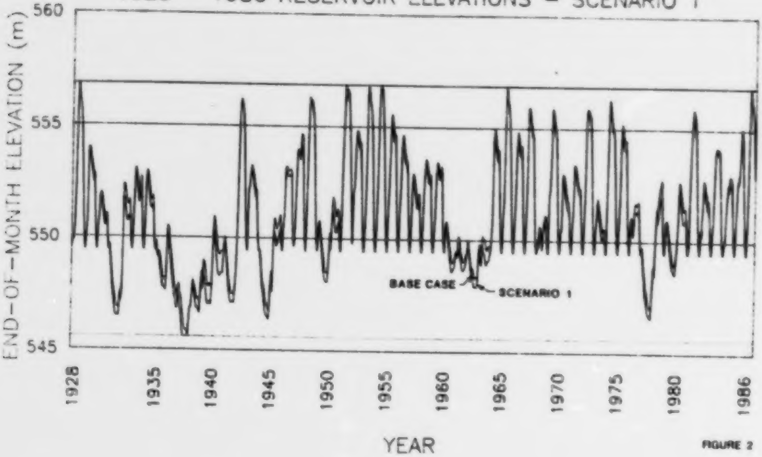

FIGURE 2

LAKE DIEFENBAKER

1928 – 1986 RESERVOIR ELEVATIONS – SCENARIO 2

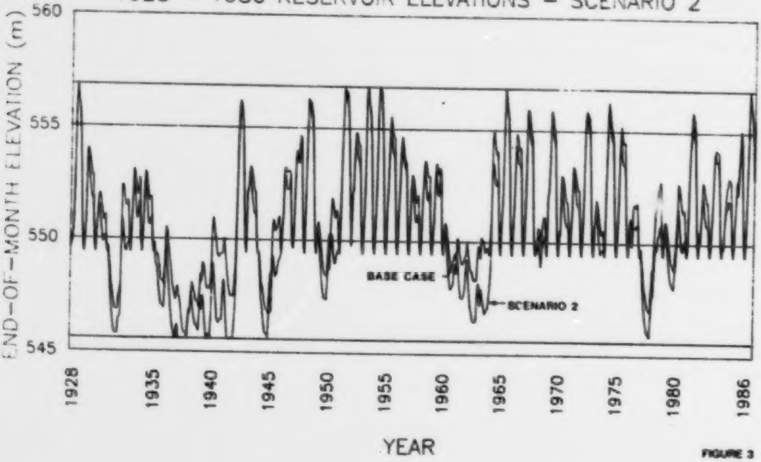

FIGURE 3

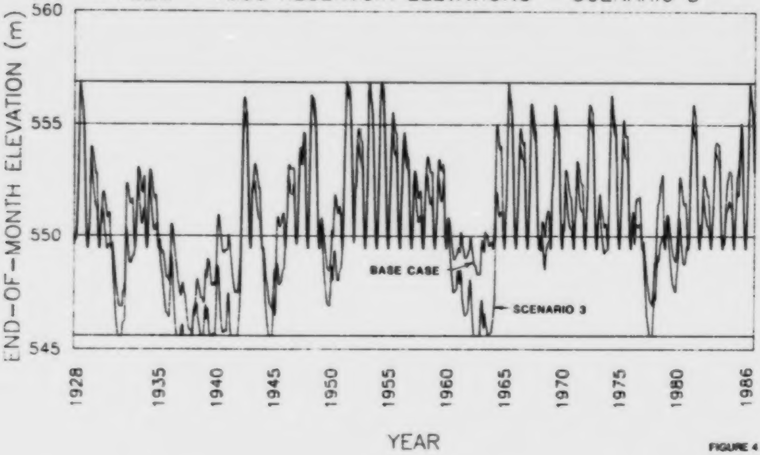

FIGURE 4

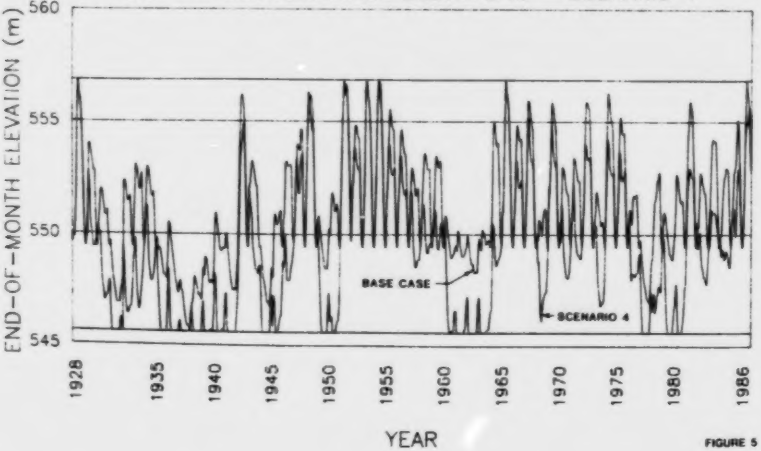

FIGURE 5

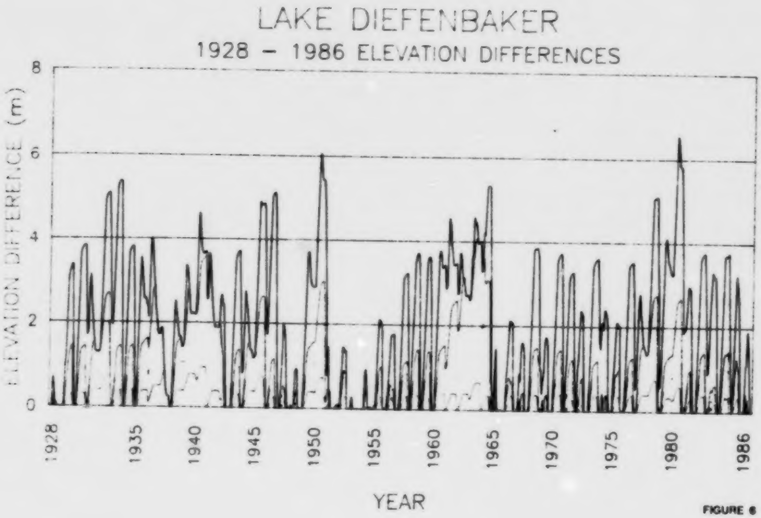

FIGURE 6

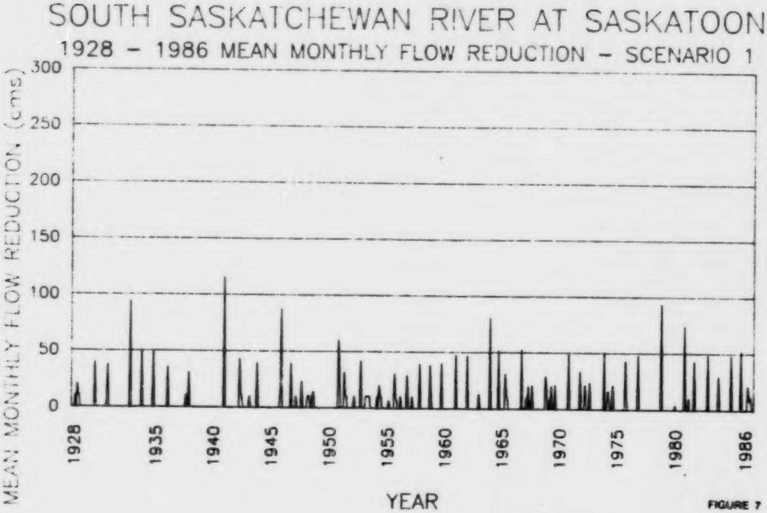

FIGURE 7

SOUTH SASKATCHEWAN RIVER AT SASKATOON

1928 – 1986 MEAN MONTHLY FLOW REDUCTION – SCENARIO 2

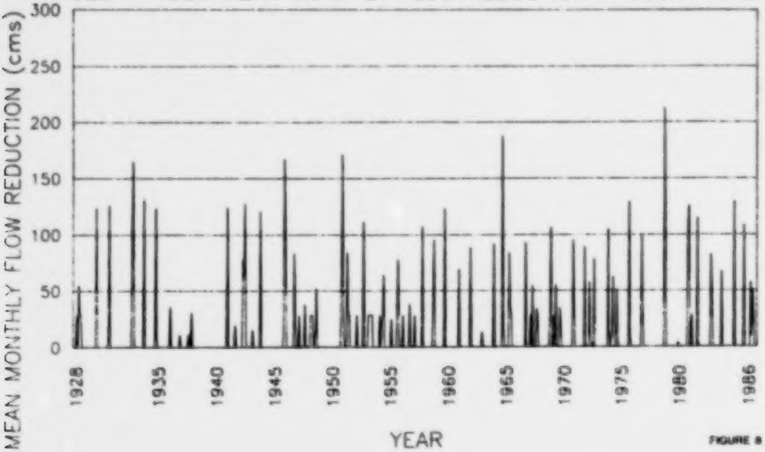

FIGURE 8

SOUTH SASKATCHEWAN RIVER AT SASKATOON

1928 – 1986 MEAN MONTHLY FLOW REDUCTION – SCENARIO 3

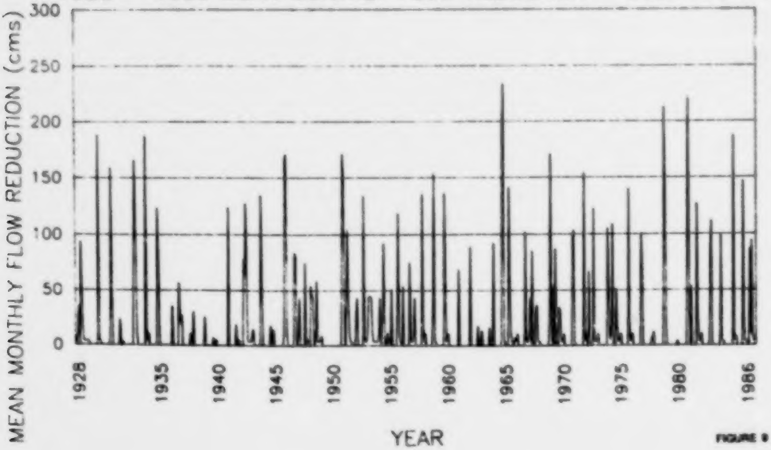

FIGURE 9

SOUTH SASKATCHEWAN RIVER AT SASKATOON

1928 – 1986 MEAN MONTHLY FLOW REDUCTION – SCENARIO 4

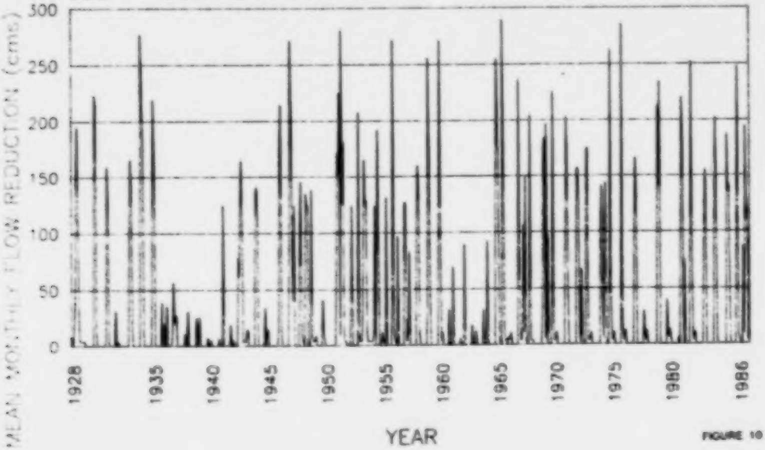

FIGURE 10

SASKATCHEWAN RIVER AT MANITOBA BOUNDARY

1928 – 1986 AVERAGE ANNUAL FLOW – SCENARIO 4

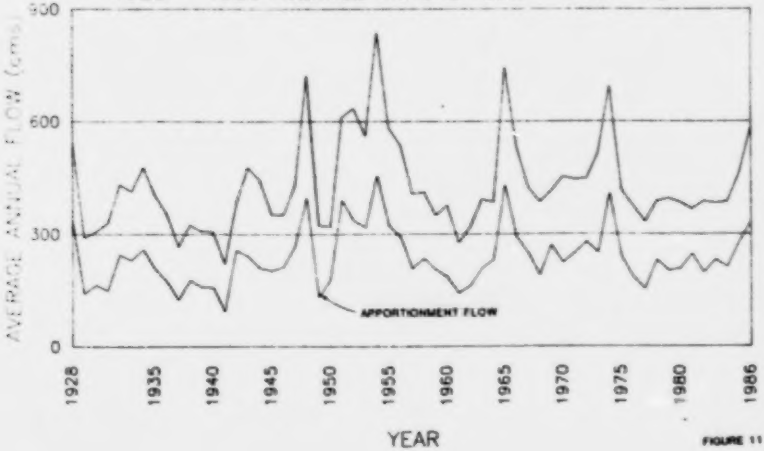

FIGURE 11

LONG TERM EFFECTS OF AN INTERBASIN DIVERSION ON THE MILK RIVER

D.G. McLean[1] and G.R.E. Beckstead[2]

ABSTRACT

Diversion of flow from the St. Mary River into the Milk River Basin commenced in 1917 and has had a pronounced effect on the receiving channel. The impact of this diverison on the morphology of the Milk River was assessed by comparing historical surveys and air photographs and analyzing available hydrologic and suspended sediment data. The major effects of the diversion included channel widening, increased cutoff activity and increased sediment yield.

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INTRODUCTION

Interbasin diversion projects have been carried out in Canada for hydroelectric and irrigation development. Assessing the environmental impacts of future projects will require reliable predictions of the physical changes to the sending and receiving streams. Unfortunately, river processes are complex and only poorly understood so that the expected channel adjustments often can not be predicted analytically. However, the lack of theoretical methods may be partly overcome by using documented case histories from similar engineering projects. Examples of this approach are illustrated in the study of Kellerhals et al. (1979) where eleven major interbasin diversions were investigated and a classification scheme was developed for evaluating their effects.

This study, a continuation of earlier work by the authors. (McLean and Beckstead, 1981), describes the impact of the St. Mary diversion into the Milk River. The project commenced in 1917 making it probably the oldest interbasin diversion in Canada. The project is unusual because an extensive channel survey was carried out in 1915 on the Milk River to monitor the impact of the diversion. Repeat surveys in 1979 and 1980 and historical air photography have provided some means of measuring the longterm channel changes along the river. This data has allowed some conclusions to be drawn on the reliability of available methods for predicting channel adjustments due to longterm changes in flow regime.

PHYSICAL SETTING

Most of the Milk River Basin consists of rolling prairie grasslands. Precipitation averages only 300-400 mm per year with about two thirds of this amount occurring between April and August. Periods of high runoff can occur in late March and April due to snow melt and between June and July due to intense localized rainstorms.

The North Milk River flows as a misfit stream along the course of a glacial meltwater channel, (Williams and Dyer, 1930). In addition, several very large abandoned coulees enter the mainstream of the Milk River below the town of Milk River (Figure 1). Downstream of Writing-on-Stone Park, the Milk River flows in a box canyon up to 1600 m wide and 150 m deep.

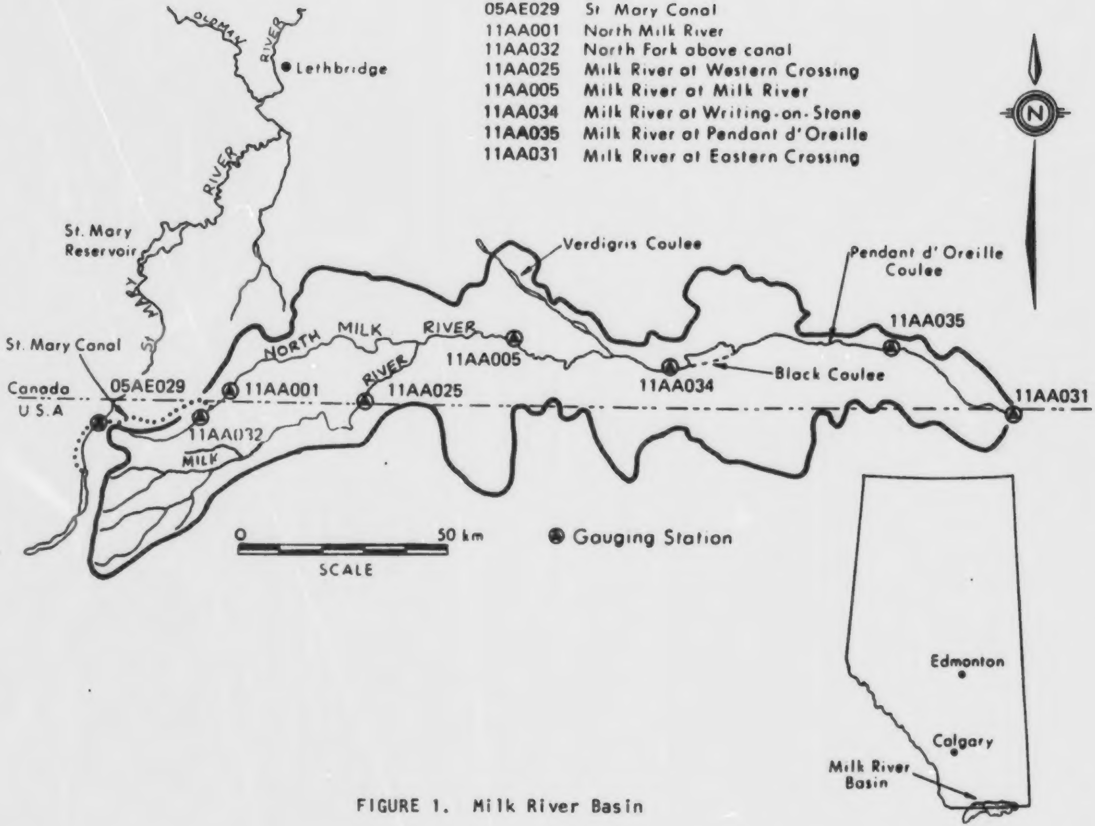

05AE029 St Mary Canal
11AA001 North Milk River
11AA032 North Fork above canal
11AA025 Milk River at Western Crossing
11AA005 Milk River at Milk River
11AA034 Milk River at Writing-on-Stone
11AA035 Milk River at Pendant d'Oreille
11AA031 Milk River at Eastern Crossing
N
Oldman River
Lethbridge
St. Mary River
St. Mary Reservoir
St. Mary Canal
Canada
U.S.A
05AE029
11AA001
11AA032
Milk
North Milk River
River
11AA025
11AA005
Verdigris Coulee
11AA034
Black Coulee
Pendant d' Oreille Coulee
11AA035
11AA031
0
50 km
SCALE
Gauging Station
Edmonton
Calgary
Milk River Basin

FIGURE 1. Milk River Basin

PROJECT DESCRIPTION

The St. Mary - Milk River diversion was initiated as part of the Boundary Waters Treaty of 1909 between the United States and Canada. Water from the St. Mary River is conveyed by a canal to the North Milk River in Montana (Figure 1). After crossing the International Boundary the water flows 80 km before meeting the larger unregulated south branch. The combined north and south branches form the main stem Milk River which flows an additional 235 km eastwards before re-entering the United States at the Eastern Crossing.

The study area has been sub-divided into four major reaches:

- the regulated portion of the North Milk River
- the unregulated south branch
- the regulated Upper Milk River from the North Milk River confluence to Writing-on-Stone Park
- the regulated Lower Milk River which extends to the Eastern Crossing on the Alberta-Montana border.

Some of the physical characteristics of these reaches are summarized in Table 1.

Due to a combination of erodible valley wall deposits, lack of vegetation and the occurrence of hydraulic piping in the canyon walls, extensive area of badlands have developed along the Lower Milk River. These areas contribute large quantities of sand and silt sized sediments to the river (Barendregt and Ongley, 1979).

AVAILABLE DATA

The earliest surveys of the river are the legal surveys of 1898-1906 (Alberta) and 1906 (Montana). In 1909, F.H. Peters, Chief Hydrographer, Dept. of the Interior, established seven hydrometric stations along the North Milk and Milk River (Figure 1) and made estimates of bankfull channel geometry and discharge capacity (Peters, 1910). The hydrometric stations on the North Milk River (11AA001), at Milk River town (11AA005) and at the Eastern Crossing (11AA031) have been maintained over the last 70 years.

Between July 6 and November 27, 1915, Peter's crews surveyed 131 cross sections along the entire Canadian portion of the river. A detailed planimetric map was prepared showing the channel and adjacent floodplain. Bed and bank materials, vegetation and other cultural features were frequently noted.

The first air photo survey of the river was made in 1922 and photos are available for many other years.

Repeat surveys were made in 1979 and 1980 at 20 of Peter's cross sections on the North Milk River and at 26 cross section on the Milk River. Additional surveys were made at three hydrometric stations (11AA001, 11AA034 and 11AA035) in order to provide further data on channel hydraulics and bankfull flows. Sediment samples of bed and bank materials were also collected.

BASIN HYDROLOGY

Seven longterm Water Survey of Canada gauging stations have operated along the Milk River system (Figure 1). Canal inflows from the St. Mary River have been recorded continuously since 1917 during the irrigation season. Natural flows are recorded on the North Milk River 1 km upstream of the canal outlet in Montana (gauge 11AA032). Regulated flows have been recorded on the North Milk River 11 km downstream of the canal outlet (gauge 11AA001) and at four other sites on the main Milk River (Figure 1).

The corresponding natural daily discharges were computed at these stations for the period 1917 - 1976 by subtracting the recorded daily canal inflows from the measured regulated flows:

$$Q_{i_{nat}} = Q_{i_{reg.}} - Q_{i_{meas}} \qquad [1]$$

The 60 years of daily regulated and natural flows were then analyzed at each station in order to determine the impact of the diversion on the discharge regime along the river.

The main effect of the diversion has been to maintain flows in the Milk River between 10 to 20 m^3/s between May and September, averaging near 15 m^3/s between June and August (Figure 2). By comparison, natural flows would have ranged between 1-2 m^3/s on the North Milk River and about 2-10 m^3/s on the Milk River at Eastern Crossing during this same period. As a result, the mean flow on the North Milk River has been increased by close to a factor of 20 (Figure 2).

The St. Mary River diversion has also substantially altered the frequency of floods on the North Milk River, which can be illustrated by comparing the flood frequency distributions calculated at the North Milk gauge (11AA001) located downstream of the outlet (Figure 2). It is apparent that in many dry years when rainstorm and snowmelt floods have been absent, the diversion releases govern the annual flood on the river. As a result, the mean annual flood on the North Milk River has been more than doubled by the diversion. In addition to increasing the magnitude of flood flows on the North Milk River, the diversion has substantially increased the duration of high water each year. For

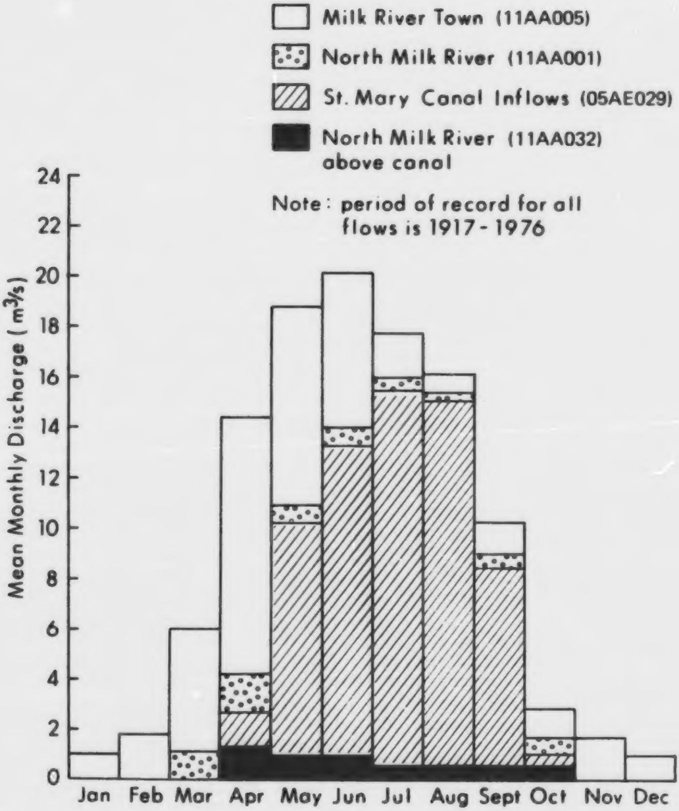


FIGURE 2a: Mean monthly flows recorded along the Milk River

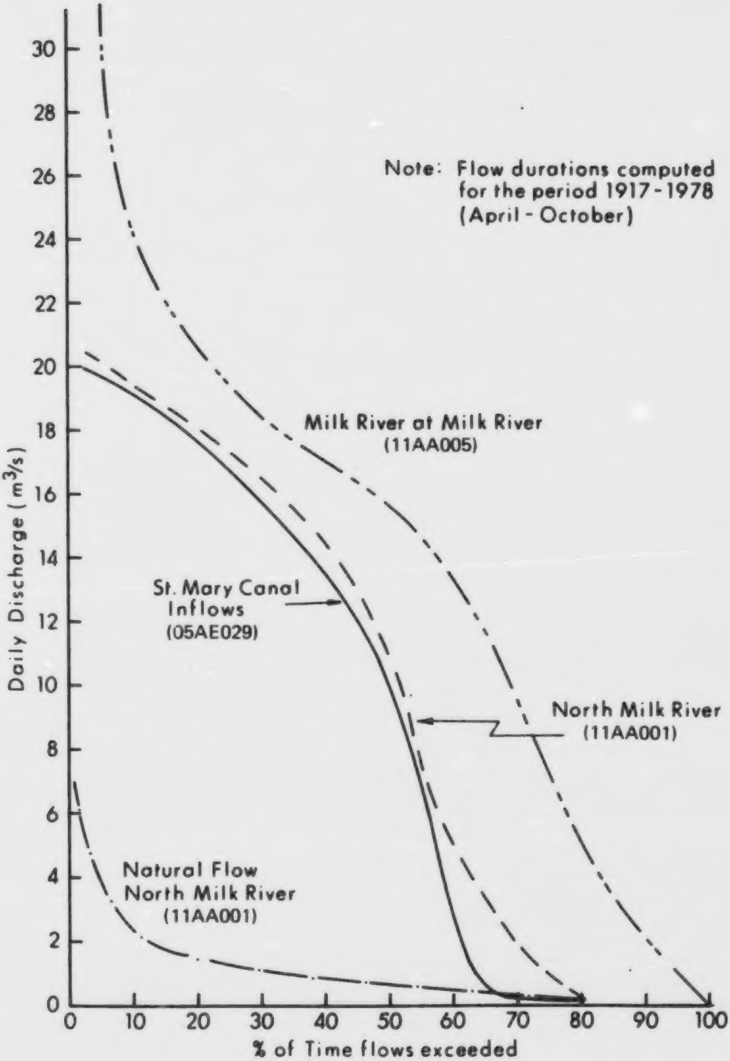


FIGURE 2b: Daily flow duration curves at Milk River gauging station

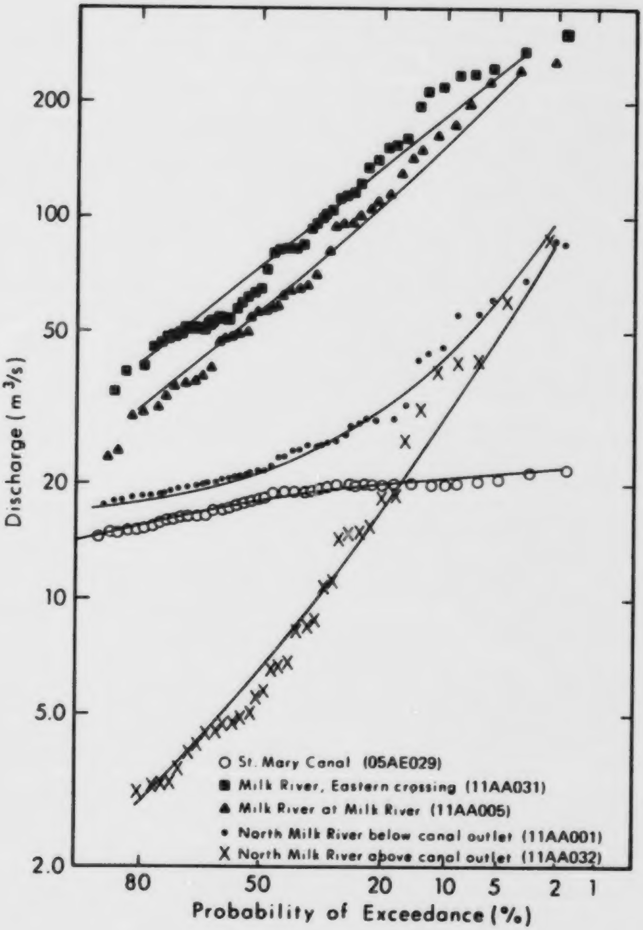


FIGURE 2c: Flood frequency curves at Milk River gauging station

example, the discharge of 15 m^3/s which has been maintained on average for three months of the year (June, July, August) would have corresponded to a 3 year flood under natural conditions. Similarly, the flow of 20 m^3/s which has been maintained on average for two weeks each year would have corresponded to about a 5 year flood in pre-diverison times. The highest flows recorded on the North Milk River have generally have been caused by rainstroms, however in many years diverison inflows have significantly increased these floods. For example, during the flood of record, roughly 20 percent was contributed by St. Mary River diversion flows.

The effect of the diversion on floods along the mainstream of the Milk River has been minor due to the much greater drainage area in this reach. The maximum recorded canal inflow of 22 m^3/s corresponds to only about 30 percent of the mean annual flood recorded at the Eastern Crossing of the Milk River (gauge 11AA031). In addition, the maximum recorded discharge at this station (300 m^3/s) was nearly 15 times greater than the largest recorded diversion flow. Therefore, although the canal has significantly increased the monthly flows along the entire river, major increases in annual floods have occurred only on the North Milk River.

PRE-DIVERSION CHANNEL CHARACTERISTICS

Prior to the diversion the North Milk River had an irregular, confined meander pattern and displayed alternating pools and riffles. The channel was composed of gravel and sand and the banks were described as predominantly sandy loam (Peters, 1910). Abandoned meander scars on the floodplain indicate that channel shifting and cutoff activity occurred prior to the diversion. Comparison of the early township surveys with Peters' maps showed five cutoffs took place, in the 15 years before the diversion started.

Based on Peters' surveys, the average bankfull width and discharge were estimated to be 23 m and 30 m^3/s respectively on the North Milk River in 1915. This discharge would have had a return period of approximately 7 years (at gauge 11AA001) under the natural flows that have occurred between 1917 - 1976.

The Upper Milk River had a meandering gravel-bed channel with silty or sandy loam banks. The channel was frequently confined by valley walls composed of stony clay or sandstone. The channel was considerably larger (bank width surveyed 52 m) than the North Milk branch due to the large drainage area contributed by the South branch (Figure 1). Peters estimated the bankfull discharge to be 48 m^3/s at Milk River town and 78 m^3/s at Writing-on-Stone Park. Our analysis of the 1915 cross-sections resulted in an average bankfull capacity of 87 m^3/s along this reach. This flow has been exceeded at least 10 times over the last 65 years which suggests the channel was not entrenched prior to the diversion project.

The Lower Milk River displayed a regular meander pattern in 1915 and contained frequent sand waves, mid-channel bars and shoals. In this sand bed reach, the average bankfull width and discharge capacity were estimated from the 1915 surveys to be 75 m and 225 m^3/s respectively. These values were found to be in close agreement to Peters' original estimates at the Eastern Crossing gauge.

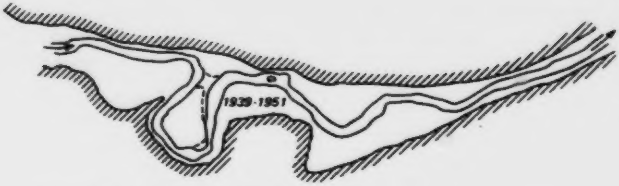
IMPACTS ON NORTH MILK RIVER

The greatest impacts from the diversion occurred on the North Milk River where the magnitude and duration of floods were significantly increased. Comparison of the 1915 floodplain maps with historical air photographs and recent topographic maps showed 35 cutoffs occurred along the North Milk River after the diversion started. As a result, nearly 25% of all meanders present in 1915 have developed cutoffs. Approximately 80% occurred as neck cutoffs due to channel enlargement or progressive channel migration. The remainder occurred by irregular channel shifts or chute cutoffs. Some examples of these kinds of channel changes are shown in Figure 3.

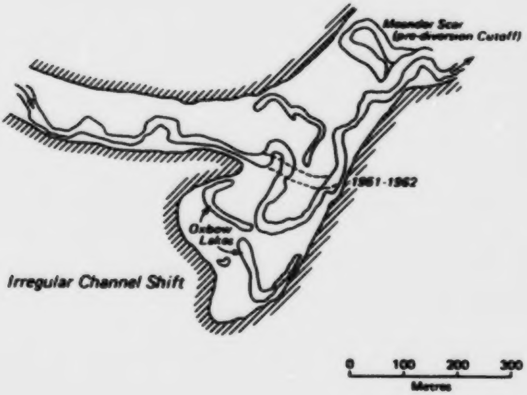
The tendency for any particular meander bend to develop a cutoff was strongly related to the meander's geometry at the time of diversion start-up. The best indicator of meander stability was found to be the initial (1915) meander neck width (Figure 4). Approximately 80% of all meanders having neck widths greater than 40 m developed cutoffs. Many of the smaller meander bends cutoff directly as a result of channel enlargement in the first 20 years after the diversion started (Figure 4). The cutoffs on the larger meanders took place 35 to 60 years after the diversion commenced and developed as a result of progressive channel migration.

The main effect of the cutoffs has been to decrease the channel sinuosity by about 7% and to increase the overall channel slope.

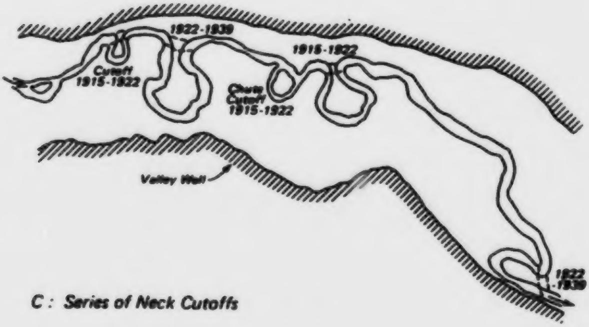
Comparison of the channel cross-section surveys showed the average bankfull width on the North Milk River increased from 23 m (range 14-32 m) in 1915 to 31 m (range 23-38 m) in 1980 (Table 1). A paired t-test on the difference between channel widths showed this increase was statistically significant at $\alpha = 0.01$. The average bankfull discharge capacity of the North Milk River channel increased from 33 m^3/s in 1915 to 83 m^3/s in 1980. As a result, bankfull discharge is now exceeded only very rarely (about once in 30 years at gauge 11AA001). The increase in channel capacity resulted mainly from enlargement of the



A : Neck Cutoff producing Oxbow Lake


Meander Scar
(pre-diversion Cutoff)
1961-1962
Oxbow
Lakes
0
100
200
300
Metres

B : Irregular Channel Shift


1922-1939
1915-1922
Cutoff
1915-1922
Chute
Cutoff
1915-1922
Valley Wall
1922
-1939

C : Series of Neck Cutoffs

FIGURE 3. Examples of channel shifts along the North Milk River.

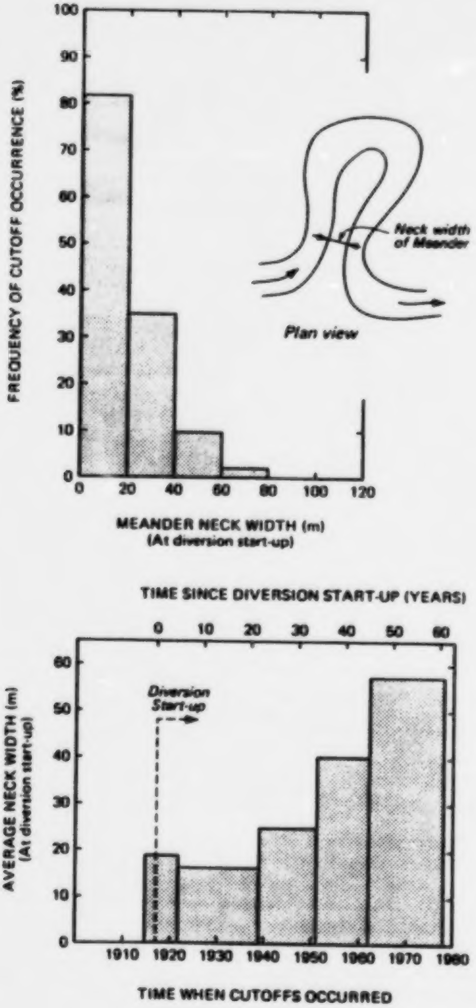


FIGURE 4. Summary of cutoff developments along the North Milk River.

channel cross-section due to widening (Figure 5). Some cross-sections indicated bankfull stage had also increased along the channel due to overbank sedimentation. Comparison of bed elevations showed that general degradation has not occurred along the river. The lack of significant degradation is probably mainly due to the presence of relatively coarse gravel sediments in the streambed. The channel bed presently has an armoured surface with a median size of about 45 mm while the median sub-surface material ranges from 15-35 mm. Critical tractive force calculations suggest the channel bed is now inactive when the discharge is less than 20 m^3/s. This flow has an annual return period of 1.5 years at gauge 11AA001 and corresponds roughly to the peak outflow from the canal.

Table 1. Comparison of Bankfull Channel Properties
Surveyed in 1915 and 1980

Reach	Year	Channel A (m^2)	Area C.V.	Top W (m)	Width C.V.	Mean Depth d (m)	Bankfull Discharge (m^3/s)	Slope
North Milk River	1915	21	0.55	23	0.31	0.91	30	0.003
	1980	45	0.34	31	0.26	1.45	85	0.0035
Upper Milk River	1915	77	0.53	56	0.26	1.38	87	0.0013
	1980	81	0.34	56	0.18	1.43	81	0.0013
Lower Milk River	1915	133	0.22	75	0.27	1.78	225	0.0007
	1980	177	0.46	88	0.27	1.93	260	0.0006

C.V. = coefficient of variation (standard deviation/mean)

Figure 6 illustrates the time scales required for some of the channel changes to take place. Unfortunately, intermediate width changes between 1915 and 1980 are not known. Changes in sinuosity and cutoff activity were estimated from historical air photos, while shifts in the stage-discharge relation (specific gauge plot) at the North Milk River hydrometric station were reproduced from Kerber (1978). The specific gauge plot in Figure 6 shows that for a given discharge, the

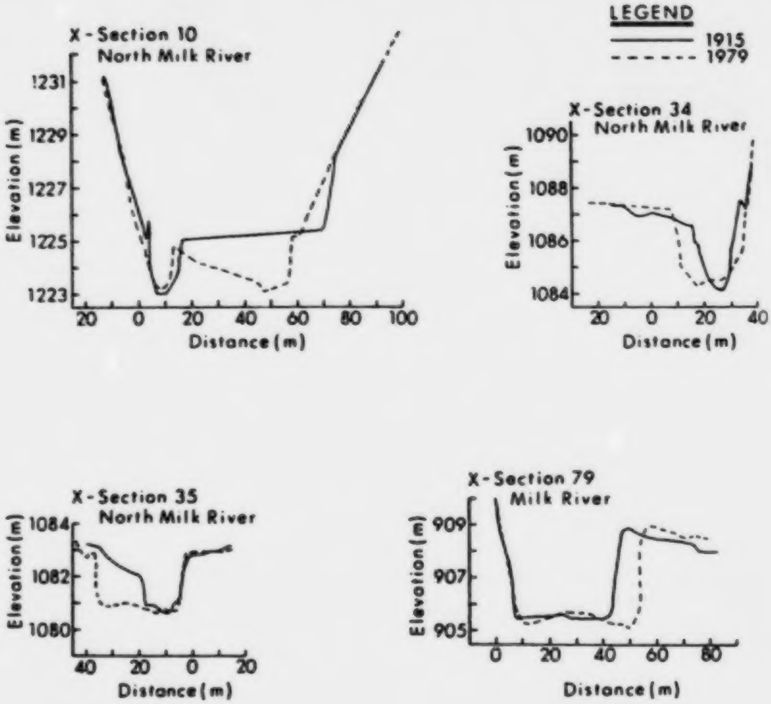


FIGURE 5. Cross-section changes on North Milk and Milk River, 1915-1979.

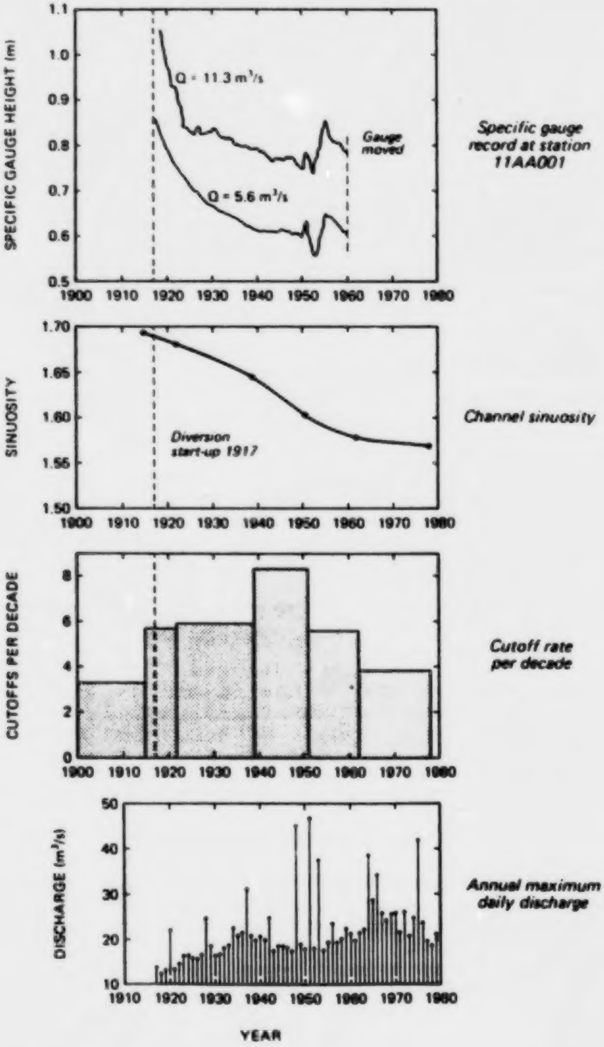


FIGURE 6. Summary of channel changes along the North Milk River.

water level at the gauge lowered systematically between 1917 and 1937. It is believed that this shift reflects the increase in the river's channel width rather than degradation.

The most active period for cutoffs and sinuosity changes occurred between 1939 and 1952, up to 35 years after the project had started. This lag time may represent the period required for the channel pattern to respond to the change in flow regime. For example, since most cutoffs developed by channel enlargment or channel migration rather than by abrupt shifts, a period of decades was required before conditions were reached where cutoffs could develop. It is expected that this lag time depended in part on the history of annual floods following the diversion start-up. If a number of large floods had occurred shortly after the diversion started, the adjustment time of the river might have been faster. In fact, the period of peak cutoff activity corresponds with the time of the flood of record on the river. Other later extreme floods in 1964 and 1975 had no significant impact on the channel pattern since, by this time, most of the short radius bends had already been destroyed.

CHANNEL CHANGES ON THE MAINSTEM MILK RIVER

Comparison of the historical air photos and maps showed no major channel pattern changes or cutoff activity occurred on the mainstem Milk River between 1915 and 1980. Furthermore, no long term channel pattern changes were observed on the unregulated South branch.

The repeat channel surveys showed no change in width occurred along the gravel bed Upper Milk River between 1915 and 1980. Some widening was measured along the sand bed Lower Milk River, although these changes were not statistically significant (at $\alpha = 0.01$). Net aggradation of approximately 0.5 m was also measured along this lower reach. A specific gauge analysis at the Eastern Crossing hydrometric station also showed evidence of net aggradation (Kerber, 1978). It is not known whether this aggradation is related to the diversion, or to the presence of Fresno Reservoir downstream in Montana or to natural processes.

IMPACT ON SEDIMENT YIELD

The Milk River was named by the American explorers Lewis and Clark on account of its high sediment concentrations during spring runoff (Holmgren, 1976). Their journal entry for May 8, 1805 states:

> "The waters of the river possess a peculiar whiteness being about the colour of a cup of tea with the admixture of a tablespoon of Milk. From the colour of its waters, we called it Milk River."

The first suspended load measurements were collected in 1905 and 1906 at Havre, Montana, 85 km downstream of the Eastern Crossing near its confluence with the Missouri River (Dole and Stabler, 1909; Stabler, 1911). These pre-diversion measurements, which were collected during relatively low flows, provided an estimated sediment load of 300,000 tonnes/year. Additional suspended load measurements were collected at Havre in 1930 and 1931 to provide estimaes of sedimentation in Fresno Reservoir (U.S. Engineering Dept., 1933). These measurements indicated seasonal loads of 205,000 tonnes in 1930 and 300,000 tonnes in 1931.

Water Survey of Canada began collecting miscellaneous suspended sediment measurements in 1975 at the Eastern Crossing, at Milk River town and at the North Milk River gauge. In 1981, the sediment load (March to October) increased from 90,200 tonnes at Milk River town to over 612,300 tonnes at the Eastern Crossing. This six-fold increase in sediment load took place over a distance of 120 km and clearly reflects the contribution of the badlands along the river's lower canyon. The daily measurements showed even minor local rainstorms produced large pulses of sediment (Figure 7). These short term pulses accounted for more than 50% of the total suspended load measured in 1981.

By comparison, the repeat channel surveys between 1915 and 1980 indicated the net bank erosion along the North Milk River totalled $1.5 \times 10^6 m^3$ which corresponds to an annual sediment yield of approximately 4×10^4 tonnes/year. The total diversion discharge volume in this period was $1.12 \times 10^{10} m^3$.

Therefore, it appears the net bank erosion along the North Milk River has constituted only a small fraction (less than 10%) of the total sediment yield in the Milk River basin. The most important sediment sources in the basin appear to be situated along the lower reach of the river in the badlands.

INTERPRETATION OF RESULTS

The changes in meander pattern, channel width and bankfull capacity observed on the North Milk River are interpreted to represent the long term response of the channel to the increased discharges from the diversion. It appears the North Milk River required more than 50 years to adjust its channel pattern to the change in the discharge regime.

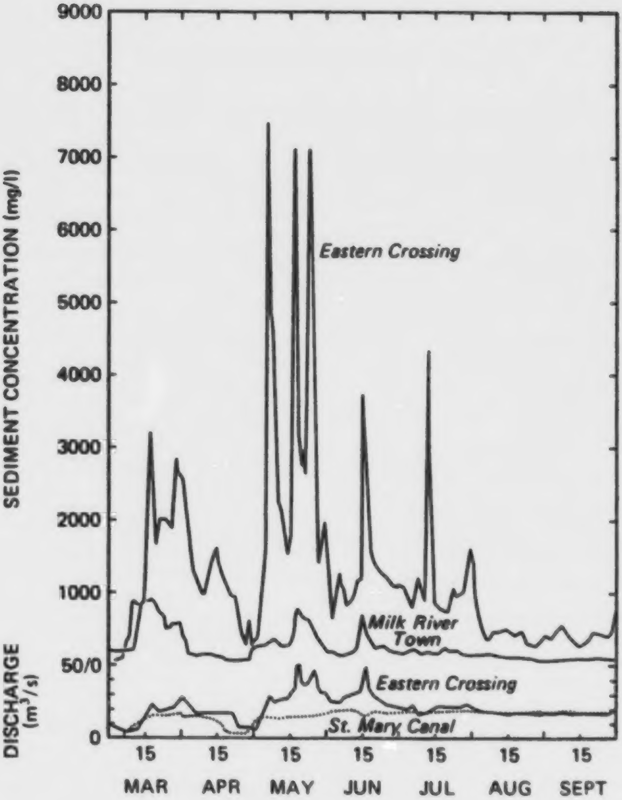


FIGURE 7. Variations in suspended sediment concentration along the Milk River in 1981.

Many other factors such as extreme floods, changes in upstream sediment supply or other engineering works could also induce changes in channel morphology. Therefore, it is obvious that natural variations in channel morphology have been superimposed on any changes induced from the diversion. It is important to consider whether these natural variations could account for the changes observed on the North Milk River. However, the relatively stable channel pattern and channel geometry observed over the last 65 years on the Upper Milk River and the South branch provide some indication that the substantial morphologic changes on the North Milk River are primarily a result of the diversion.

The diversion does not appear to have induced significant channel changes on the mainstream of the Milk River, where the canal inflows are less than 10% of the naturally occurring annual flood flows. Therefore, it appears that on the Milk River system, the morphology has been controlled by the magnitude of the flood flows (which occur only a few days each year) are not by the mean annual flow characteristics.

PREDICTING THE EFFECTS OF THE DIVERSION

F.H. Peters made a qualitative assessment on the effects of the diversion in 1910. Some of his major conclusions are as follows (Peters, 1910):

> "If this volume of water was turned into the North branch... the North Milk River would be running with banks practically full and the velocity of the stream would...create a very heavy scour. The river banks are everywhere of soft material which is liable to erosion and in a short time the river channel would adopt itself naturally to the new conditions of flow. This would mean a decided change in its average cross-section and also the river channel would change its course in many places."

Also, "the passage of this extra volume of water...would, particularly on the North branch, have the effect of enlarging the channel and would therefore lessen the tendency of the river to overflow its banks during flood."

Peters also concluded that changes on the Milk River would be less radical than on the North Milk because its channel was considerably larger.

The channel widening, increased cutoff activity and channel entrenchment that have been observed since 1915 along the North Milk River verify Peters' early predictions.

Since Peters' time, a number of semi-theoretical and empirical regime relations have been developed for predicting the hydraulic geometry of gravel-bed rivers (Bray, 1973; Parker, 1979). These equations consist of simple power functions

[2] $$X = aQ^z$$

where X is a channel parameter such as average width, mean depth or mean velocity and Q is the "dominant" or channel forming discharge. In the case of Parker's equations, X and Q are non-dimensionalized parameters which incorporate the influence of sediment size. The dominant discharge is generally considered to be a relatively frequently occurring flood with a return period of about 2.0 years (Bray, 1973). This corresponds to a discharge of 22 m^3/s on the North Milk River and is close to the maximum canal inflow (Figure 2).

An alternative approach is to use the regime equations as scaling relations which eliminates the constant in the power functions. In this form, the equation are:

[3] $$X_2/X_1 = (Q_2/Q_1)^z$$

where X_1 represents the pre-diversion channel characteristics measured at the pre-diversion dominant discharge Q_1 and X_2 represents the post-diversion channel characteristics at the new discharge Q_2. The pre-diversion 2 year flood on the North Milk River was estimated to be about 10 m^3/s.

The measured and predicted hydraulic geometry of the North Milk River are summarized in Table 2. Bray's equations provided the best estimates with the predicted values being within 10% of the measurements. This close agreement is not surprising since Bray's equations were developed from studies on Alberta gravel rivers, including the Milk River at the town of Milk River.

Table 2. Comparison of Measured and Predicted Hydraulic Geometry on the North Milk River

Method	Discharge (m^3/s)	Area (m^2)	Top Width (m)	Mean Depth (m)	Mean Velocity (m/s)	Slope
1915 meas.	10	10.2	14.5	0.70	1.00	0.0030
1915 meas.	22	15.8	17.5	0.90	1.40	0.0030
1980 meas.	22	18.3	27.0	0.68	1.20	0.0035
Bray	22		24.2	0.74	1.22	0.0036
Parker	22		20.6	0.57	1.71	0.0046

Note: 2 year annual flood (natural flow) = 10 m^3/s
2 year annual flood (regulated flow) = 22 m^3/s)

Therefore, these regime equations appear to provide reasonably reliable estimates of the long term change in average channel geometry. However, the relations do not provide any estimate of the time period required for the channel changes to occur.

It would be much more difficult to predict the cutoff activity and changes in channel pattern that have occurred along the North Milk River. An assessment of these changes would still be based primarily on interpretive skills and a general understanding of river geomorphology. The problem is complicated by the fact that the channel is often confined by non-alluvial deposits such as glacial till and bedrock. As a result, rates of bank erosion would be very difficult to predict and very variable along the river. It should be pointed out that one-dimensional mathematical models such as the sediment routing program HEC-6 do not consider any lateral channel processes such as bank erosion or meandering. However, planform changes were the dominant channel response on the North Milk River. Therefore, such mathematical models would not be very useful for predicting the impacts from a diversion project.

CONCLUSIONS

The St. Mary diversion induced substantial channel enlargment and cutoff activity on the North Milk River. The greatest cutoff activity occurred up to 35 years after the diversion started. This interval could be interpreted as the time required for the channel pattern to respond to the change in flow regime.

Some of the average cross-sectional changes observed on the North Milk River could have been predicted quite closely from simple empirical regime methods. However, the cutoff activity and time period required for channel changes to occur could not have been predicted at the present time. Present-day one-dimentional mathematical models would not have provided very useful predictions since most channel changes involved adjustments to the river's planform.

The results of this study reinforce the conclusion of Kellerhals et al. (1979) that there is a need to collect systematic long term observations of river channel changes following the construction of major river engineering projects. Such observations could improve our predictive capabilities by providing useful case histories and empirical experience. In addition, long term measurements of channel changes will be necessary to verify and calibrate future mathematical models if they ever become available. The pioneering work of F.H. Peters deserves recognition because he clearly foresaw the need for such studies.

For future projects, more attention should be given to the design of long term monitoring programs. In particular, future study programs should be designed to distinguish changes induced by the project from the naturally occurring channel changes that may occur over many decades. This will involve conducting additional surveys on the unregulated portions of the river or on nearby unregulated streams. This "paired watershed" approach was described by Church (1981) and was used to investigate the impact of the Kemano River diversion in British Columbia.

ACKNOWLEDGEMENTS

The majority of work reported herein was carried out while the authors were employed at the Alberta Research Council (McLean) and Alberta Environment (Beckstead).

Unpublished suspended sediment data and copies of Peters' 1915 floodplain maps were provided by the Calgary office of Water Survey of Canada. The original 1915 field survey notebooks were provided by Alberta Transportation, Surveys and Mapping Branch. Some of the cross-sections on the North Milk River were collected by the

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POTENTIAL CLIMATIC IMPACTS OF WATER TRANSFERS

F.J. Eley and R.G. Lawford[1]

ABSTRACT

The mechanisms by which water transfer activity can cause climate change are reviewed, with respect to the various scales of water transfer projects which have been proposed or carried out. The potential effects of very large water transfers (large regional irrigation or ocean current manipulation) are also summarized.

The possible effects of the creation of Lake Diefenbaker in central Saskatchewan on summer precipitation are discussed in detail. The possible climatic and oceanographic effects of diverting water from James Bay to the Great Lakes are also described. The paper concludes with a brief review of the possible effects of climatic change on the planning and assessment of water diversions and some recommendations for further research.

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INTRODUCTION

Canada diverts more water than any other country in the world (Quinn, 1981). From time to time additional diversions are proposed. Some of these proposals are larger than any existing diversions, and their potential influence on the environment has not been fully elaborated. Major water diversions alter the hydrologic cycle and as a consequence, they can affect the climate.

Climate is influenced by changes in the amount of water surface or wet surface in the source, transit and destination regions of the water diversion. The surface may be changed from ice, vegetated or dry land to water or a wetted surface. The area of wetted surface controls the rate of evaporation and consequently the energy required to evaporate water. In northern Canada the dominant process is sensible heat transfer from cold water to very cold air with minimal moisture holding capacity. Local climates are changed by these processes. For example, removing water from northern rivers and lakes can increase the amount of ice cover or the length of the ice-cover season.

Major water diversions are made for a variety of purposes. The purpose determines the nature of the diversion and hence the degree and kind of climate impacts which occur. The most common reasons for existing water diversions are to increase hydroelectric power production, to provide canal water for navigation, to provide water for irrigation and to provide a medium to carry away wastes or waste heat. Hydroelectric developments and canal diversions have very little effect on the climate because the water is kept in narrow channels and usually returned to its original drainage system. Irrigation changes the climate over irrigated fields, and can sometimes affect a larger region. A very large water diversion has been proposed for the purpose of climate modification--by warming the Arctic ocean (Borisov, 1973).

The climate changes caused by existing water diversions are small and are usually considered of little consequence. As water transfers of large magnitude become more common, climatic effects will become more significant and more extensive. Water transfer proposals to intentionally change climate can be considered as extreme cases.

SCALES OF WATER DIVERSION AND THEIR CLIMATE EFFECTS

In order to systematically review their effects, water diversions have been classified according to the amount of water diverted. The probable reaches of their detectable climatic influence have been estimated from the literature (Figure 1). The primary changes associated with water diversions occur in surface albedo, evaporation rate and surface temperature. Important, less direct, influences may be felt on sea surface conditions far from the project site. Table 1 shows the general effects expected from moving large volumes of water within Canada or from Canada southward into the warmer and drier sub-tropical latitudes. It should be noted that due to the seasonal variations in the differences between water temperatures and the overlying air temperatures, the magnitudes and even the sign of these changes may vary from season to season.

Table 1. Effects on climatic parameters

SOURCE	TRANSIT	RECEPTOR	
PARAMETER	REGION	REGION	REGION
Temperature	+/-	+/-	-/+
Humidity	-	+/-	+
Cloud/fog	-	+/-	+
Precipitation	-	NEG.	+/-
Ice-free season	-	+	NEG.

(NEG. indicates a negligible effect)

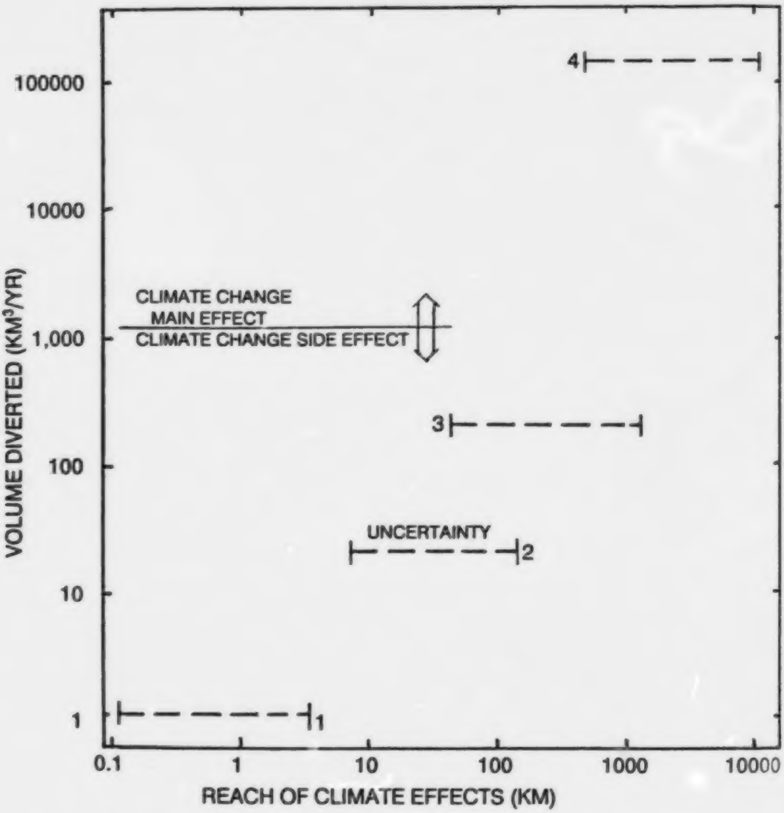
Small Scale (Water transfer of less than 10 km^3 per year or wetted area less than 1000 km^2)

Small-scale water diversions may be considered as those whose climate effects will be local, not extending in measurable form beyond a few kilometres from the area modified as a result of the diversion. The amount of water diverted will be under about 10 km^3 per year (10 million dam^3/year). Reservoirs or wetted areas with surface area of less than 1000 km^2 are also considered in this category. At these scales, the degree of dispersion has a dominant effect on the fate of modified air. For example, in unstable atmospheric conditions, the humidity which is measurably modified over an irrigated field or a lake may not be detectably changed at a distance of only a hundred metres from the source. On the other hand, under stable conditions, enhanced humidity or reduced temperature will be detectable up to a few kilometres from the moisture source. There have been many studies of the microclimate of irrigated fields. Davenport and Hudson (1967) reported on a study specifically designed to assess the distances over which irrigation affected the evapotranspiration rates downwind of the irrigated area at a site in the Sudan and at a second site in England. They found that the air dries nearly to upstream conditions within a few hundred metres downwind of a 300 m wide irrigated field , although a small measurable residual persists for as much as several kilometres.

In the early 1970's, several investigators tried to determine the climatic effects of a large new irrigation project in the interior of Washington State which used 2 to 3 km^3 of water per year. Statistical tests were run on records of temperature, precipitation and evaporation at local climate stations during the summer irrigation season. Fowler and Helvey (1974) report that the climate stations in the irrigated area showed minimal changes in temperature and summer rainfall, which were not distinguishable from natural variations. There was, however, a significant decreasing trend in measured evaporation in the region as the irrigation project developed.

Another project in the small scale range is the Jonglei Canal in the Sudan (Mageed, 1985). This canal would divert some 7 km^3 per year around the great swamp at the juncture of the two Niles. The purpose is

Figure 1. REACH OF CLIMATE EFFECTS FROM MAJOR WATER DIVERSIONS



1.	Small Scale	Single large irrigation project
2.	Medium Scale	Multi or regional irrigation project
3.	Large Scale	Continental (multi-river) project
4.	Mega Scale	Arctic Ocean diversion at Bering Strait

primarily to reduce evaporation in transit, so that more water will be available for irrigated agriculture on the downstream portion of the Nile. This project will cause some small changes in regional humidity, temperature and possibly precipitation if it is ever completed.

The climate of natural lakes can be used in assessing the effects of a man-made lake on the climate of surrounding land. Schaefer (1976), in estimating the effects of Williston Lake in British Columbia, and Buckler (1973), in estimating the effects of Lake Diefenbaker referred to the climate of existing lakes, particularly as documented in the then-recent study of the Great Lakes by Phillips (1972). Phillips showed that over half the modification of air moving over Lake Ontario occurs in the first 10 minutes over the lake surface, which translates into a distance of approximately 2 km at typical average wind speeds of 15 to 20 km/h. This scale is a typical width of a large narrow reservoir. Modifications by Lake Diefenbaker (2 to 3 km wide) were easily detected at a station 1 km downwind, but were barely detectable at a site 5 km downwind of the lake (Buckler, 1973).

Schaefer (1976) estimated the effect of regulating the Peace River on seasonal variations of humidity over the surrounding farmlands. Since water temperatures are colder than natural flows in summer and warmer in the fall, the effect is reduced evaporation from the river in summer and increased evaporation in fall and winter. The loss of ice cover in winter also influenced evaporation and led to higher frequencies of local fog and cloud.

Medium Scale (Water transfer of 10 to 100 km^3 per year or wetted area 1000 to 10,000 km^2)

For purposes of this discussion, medium scale diversions are those involving 10 to 100 km^3 of water transferred per year. Reservoirs and wetted areas of surface dimension 1000 to 10,000 km^2 are also included in this category. The climate effects of medium scale diversions will be measurable at distances of tens of kilometres from the source area. This is the scale of the GRAND Canal proposal involving the damming of James Bay and re-routing this water to the Great Lakes (Kierans, 1965). Other medium-scale diversion proposals include the diversion of several northern rivers in the U.S.S.R. to irrigate the lands around the Caspian and Aral Seas (Voropaev and Velikanov, 1985). In both cases large-scale evaporative use of water for irrigation is the main incentive for the proposal. Voropaev and Velikanov reported that Russian studies expected the climatic influence of the reservoirs and canals to extend only a few kilometres at most. In most cases the increased evaporation will not trigger measurable precipitation increases. However, it will lead to small, seasonally-dependent local changes in humidity and temperature, and in cloudiness and fog. In addition, diverting runoff from one ocean to another may cause significant effects on sea surface temperature, salinity and ocean stability.

Large Scale (Water transfer of 100 to 1000 km^3 per year or wetted area of more than 10,000 km^2)

The largest scale of water diversions proposed for North America (NAWAPA) and for the U.S.S.R. (diversion of all available water to southern agriculture) would each involve the diversion and consumption of water volumes up to 300 km^3 per year. The creation of wetted areas or reservoirs greater than 100,000 km^2 in area would also fall into this category. Such projects may change the climate measurably over large regions. The quantity of water involved in these projects is as large as natural evaporation and precipitation over large areas. For example, a volume of 300 km^3 of water is equivalent to 100 mm of additional evaporation over an area of 3 million km^2. Drozdov (1974) estimated that this additional volume of water for irrigating the Caucasus region in the southern U.S.S.R. could increase summer precipitation in the Caucasus by 100 mm per year (20 to 50 percent) and by 20 to 50 mm over a vast area of eastern Europe and western Asia. If these estimates are correct, irrigation on this scale would have the beneficial effects of higher humidity and precipitation on a sizeable neighbouring territory.

Mega Scale (Water transfer of more than 1000 km^3 per year)

The only mega scale water diversion proposed has as its primary purpose intentional climate change for the entire Northern Hemisphere. The proposal made by Borisov (1973) would involve the manipulation of the Arctic ocean currents to significantly increase heat transfer from mid-latitude waters. More than 100,000 km^3 of water would be diverted annually.

If this water diversion proceeded as proposed the Arctic Ocean would lose its permanent ice cover. This would lead to a series of complex changes in the local energy balance:

- the albedo of the sea surface would be much lower due to the removal of the ice cover;
- the albedo of the clouds would be higher than at present due to higher cloud water content;
- because of the absence of a permanent ice cover and warmer sea surface temperatures, evaporation from the sea would occur at several times its present rate, consuming significantly more energy.

The net effect of these changes has been estimated as primarily a higher winter temperature in the northern half of the Northern Hemisphere.

EFFECTS OF LAKE DIEFENBAKER

A small-scale water reservoir in central Saskatchewan was completed in 1967. It involved the construction of the Gardiner and Qu'Appelle dams and the formation of a long narrow reservoir of water known as Lake Diefenbaker. When full, Lake Diefenbaker has a length of 225 kilometers and an area of 43,000 hectares.

Long-time residents of the area have claimed that the formation of the lake has altered storm movements and the distribution of precipitation. One farmer felt that after the lake was formed storms followed a more southerly route, resulting in more precipitation for the farmers living along the valley of the South Saskatchewan River during the summer months. Mr. Law and Mr. Sheppard, two farmers in the area, have been conscientious weather observers since the early 1950's. Both farmers have recorded daily rainfall amounts during the spring, summer and fall for the past 35 years. They expressed an interest in making the data available for research on the possible effects of the lake.

In the interests of seeing whether a lake effect on precipitation could be confirmed or not, a study was carried out by the Hydrometeorological Research Division. The hypothesis that a significant change had taken place in monthly precipitation amounts observed in the vicinity of Lake Diefenbaker during the period from May to September was tested using data from both the Law and Sheppard farms and from four nearby climatological stations: Outlook, Elbow, Beechy and Pennant. The locations of these observation sites are shown in Figure 2. The data were stratified into a 13 year period (1951 - 1963) before the formation of Lake Diefenbaker and a 16 year period (1969 - 1985) after the reservoir was filled. The Student's t-test was used to assess the level of significance of the results.

The results are presented in Figure 3. They indicate that increases in average monthly precipitation occurred at all stations in July and, with one exception, at all stations in May. On the other hand, all stations but one recorded decreases in August and September. In June three stations reported increases and three reported decreases. A number of these increases and decreases were significant at the 95% confidence level.

Does this increase mean that Lake Diefenbaker is having an effect on precipitation patterns? To test this hypothesis, data for the same years from stations in three other areas around the province were examined, including sets of climate stations in the vicinity of Prince Albert, Nokomis and Weyburn. Again, increases and decreases in monthly rainfall amounts, significant at the 95% confidence limit, were observed. This analysis included the main synoptic stations surrounding the Lake Diefenbaker area: Kindersley, Saskatoon, Moose Jaw and Swift Current. Most stations showed significant changes in monthly precipitation amounts, with increases for some months and decreases in others when the periods before and after the construction of Lake Diefenbaker were compared. The data indicate that variations in monthly precipitation amounts were not unique to the area around Lake Diefenbaker. Consequently, it is not possible to attribute the effects observed in the vicinity of Lake Diefenbaker to the lake's existence.

Figure 2 LOCATIONS OF CLIMATOLOGICAL STATIONS IN THE VICINITY OF LAKE DIEFENBAKER

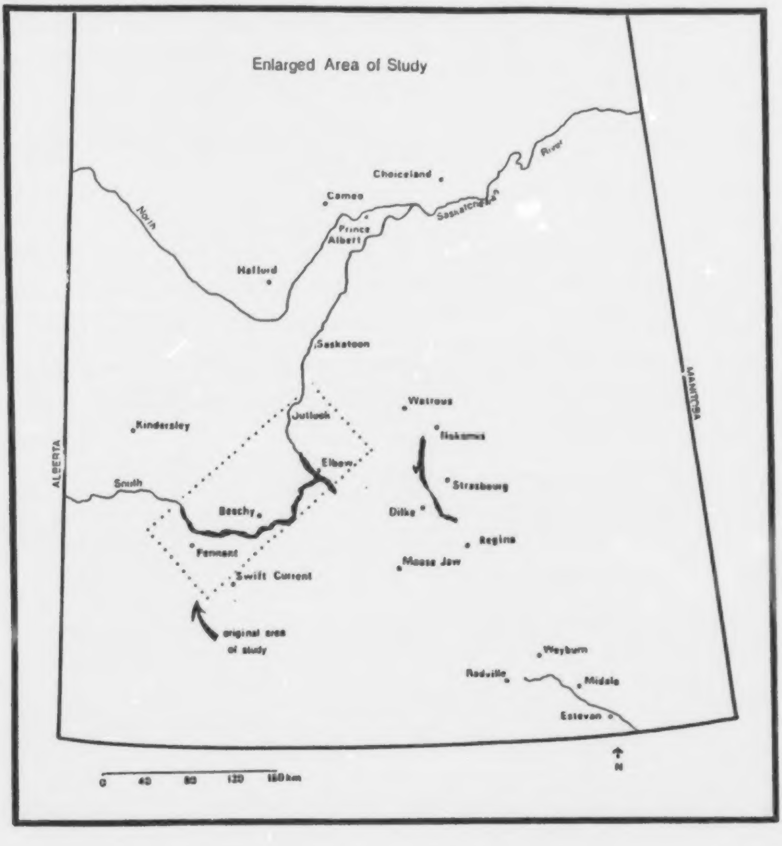
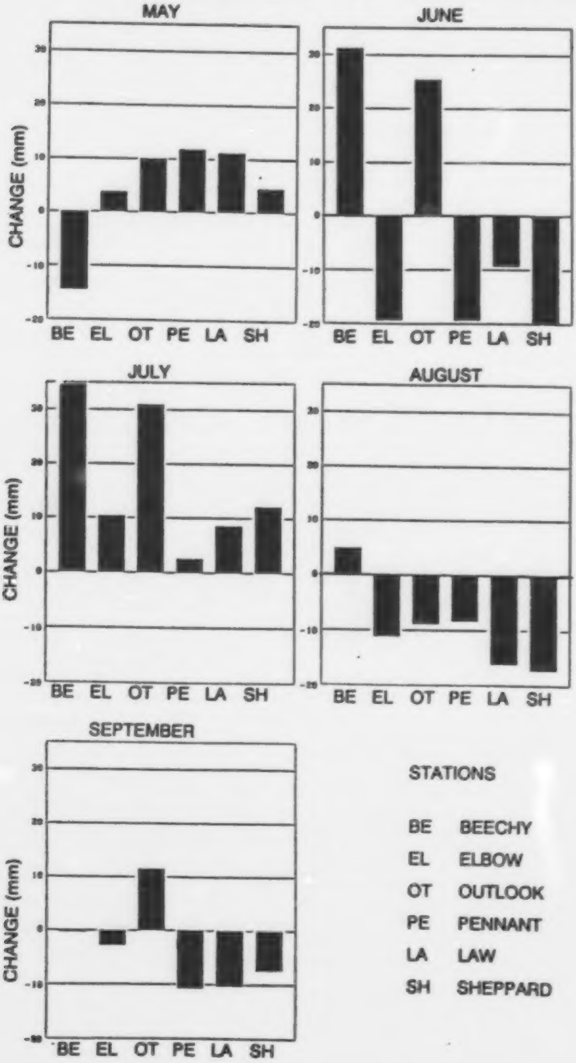

Enlarged Area of Study
Choiceland
Cameo
Prince Albert
North
Saskatchewan
River
Hafford
Saskatoon
Watrous
Outlook
Kindersley
Nokomis
ALBERTA
MANITOBA
Elbow
Strasbourg
South
Beechy
Dilke
Regina
Pennant
Moose Jaw
Swift Current
original area of study
Weyburn
Radville
Midale
Estevan
0 40 80 120 160 km
N

Figure 3 CHANGE IN MONTHLY MEAN PRECIPITATION AFTER THE CREATION OF LAKE DIEFENBAKER



Several other trends were evident in the data, including:

- a tendency for drier values to occur in the southern part of the province in June and moister values to occur in August and September after 1969.
- a tendency for the differences between monthly precipitation amounts to be less variable from station to station in the period from 1969 to 1985.

THE ROLE OF JAMES BAY RUNOFF

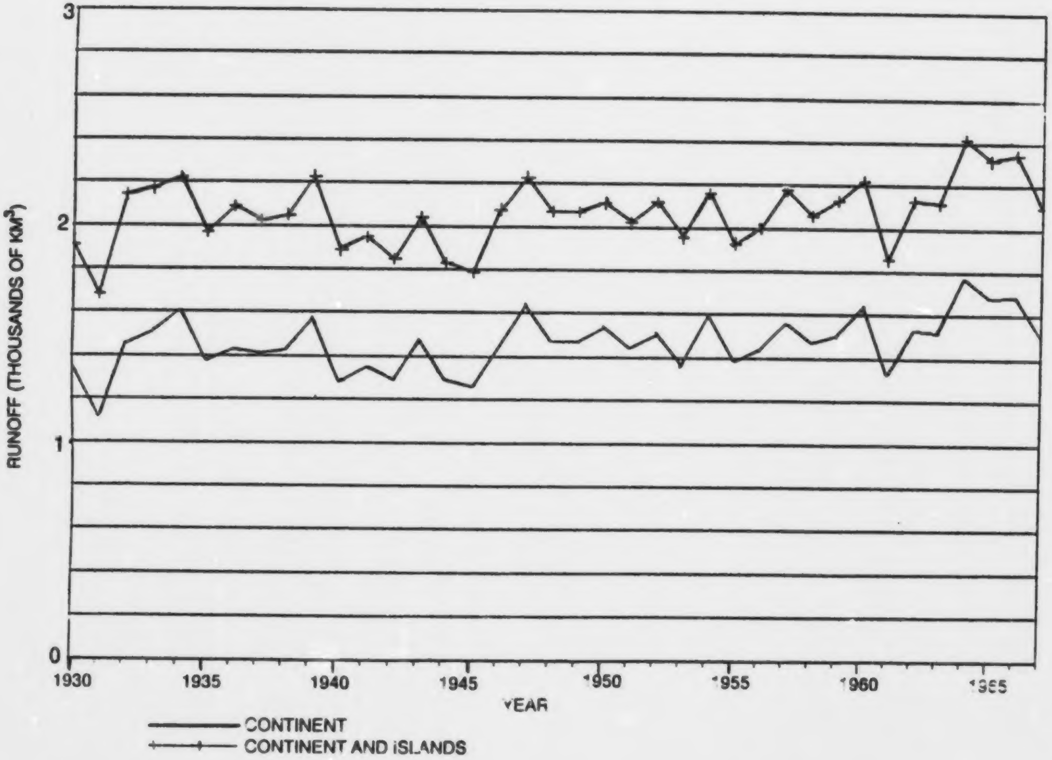
The role of runoff in modulating ocean currents and temperatures is only now beginning to be studied. Some researchers postulate that the fresh water input into high latitude surface waters, either by direct precipitation or by runoff, has a controlling influence on oceanic heat transport. There is some good circumstantial evidence to suggest that the outflow from the Arctic Ocean could have significant impacts on the North Atlantic. The evidence is reviewed in the following paragraphs and its implications for medium to large scale water diversions involving the river discharge into James Bay are assessed.

Lazier (1980) reported that there was a very significant freshening of the surface waters in the North Atlantic beginning in 1967. As a result of this freshening, which persisted for 3 years, the vertical stability of this portion of the North Atlantic increased. There is also reason to believe that the heat fluxes into the atmosphere from the North Atlantic decreased since the vertical mixing of the ocean was limited to a layer 100 m in depth.

The cause of the freshening of the North Atlantic is interesting to consider. Lazier attributed it to an Arctic High which persisted over Greenland. However, there is no way of determining whether this climatological High was the cause of the phenomenon or the result of lower heat fluxes into the atmosphere or of some upstream atmospheric phenomena.

There is another explanation for the freshening which implicates the river runoff from the North American continent. As Figure 4 shows, the runoff into the Arctic Basin from North America varies considerably from year to year. The period from 1964 to 1966 was particularly interesting as the flow into the Arctic Basin in each of these years exceeded the annual flows recorded in the earlier 30 years. The Arctic gyre moves water counter-clockwise through the basin with a period of approximately 10 years. Based on this knowledge, it could be expected that a large freshwater influx entering James Bay would take 2 to 4 years to reach the North Atlantic. The idea that the freshening of the North Atlantic is linked to Arctic melt and runoff is supported by Lazier's observation that the lowest salinity values are observed during summer when the outflow from the Arctic Ocean is the greatest (Lazier, 1980). This is contrary to conventional wisdom which suggests that the highest salinities should be observed during the summer when evaporation rates are the highest.

Figure 4 RUNOFF FROM NORTH AMERICA INTO THE ARCTIC BASIN



The question then arises as to the contribution made by the rivers flowing into James Bay to this overall runoff to the Arctic. As noted earlier, Kierans(1965) has proposed that James Bay be blocked off and this water re-routed to the Great Lakes. The total estimated contribution of these rivers to the total freshwater input to Hudson Bay is 280 to 460 km^3 or 13 to 22% of the estimated average freshwater input to the Arctic Ocean and Hudson Bay drainage from North America (UNESCO, 1978). One would anticipate that building a dam across James Bay could have the same effect on flows to the Arctic and Hudson Bay drainage as having a dry year in northern Canada. If the hypothesis elaborated in the earlier paragraphs can be supported by more extensive investigations, reducing this inflow from James Bay would lead to the accumulation of less buoyant, more highly saline water in the North Atlantic, and consequently to more vertical overturning of the ocean and larger heat and moisture transfers into the atmosphere. In years with below average precipitation when runoffs were below average this effect would be accentuated. It is not unreasonable to expect that the climate of Europe could be affected by this chain of events. In view of the limited climatic effects associated with rerouting river channels, future research may reveal that the largest climatic impacts arising from river diversions are those associated with routing freshwater inputs into another ocean.

WATER DIVERSIONS IN A CHANGING CLIMATE

Based on our consideration of existing diversions and reservoirs, it can be concluded that the variations occurring in the regional climate can often be much more significant than the local effects arising from a diversion. A knowledge of the variability of regional climates and the potential changes in global and regional climates are not only important considerations for assessing the impacts of climate change, but are also important for planning water diversions. As a result of the emissions of carbon dioxide and other radiatively active gases into the atmosphere, it is anticipated that the mean global surface temperature will increase by as much as 2 to 4 degrees C over the next 50 years. Although scientists are less definite about the impacts of the greenhouse effect on the distribution of precipitation there is concensus that precipitation patterns will change, with increases in some areas and decreases in other areas. These changes could have significant implications for water diversion plans. For example, diversions are currently designed assuming a continuity of supply based on historical data. However, if climate change led to increased evaporation and reduced stream flows, structures and reservoirs could prove to be over-designed. If, on the other hand, warmer temperatures induced more cloud cover, precipitation and increased river flows, the present structures and reservoirs could be inadequate.

The potential effects of climate change on both the Great Lakes and the La Grande Basins have been assessed based on the outputs from the GFDL (Geophysical Fluid Dynamic Laboratory) and GISS (Goddard Institute for Space Studies) global circulation models. Singh (1987) concluded that net basin supplies would be increased by 6.7 to 20.2 per cent for the La Grande, Caniapiscau and Eastmain - Opinaca River basins by projected changes in climate. On the other hand, Cohen (1986) found that the water available in the Great Lakes basin will decrease if the scenarios projected by the global circulation models are realized. While there is still a great deal of uncertainty surrounding the reliability of the outputs of the global circulation models, they do offer us some estimates of the types of impacts which are possible.

There is a need for climatologists to extend this work to basins across Canada and to determine the effects of the year-to-year and decade-to-decade variability of precipitation and temperature. Future water diversions will not only have to be designed to meet all the vagaries of the present climate but they should also accommodate the anticipated effects of climatic change scenarios on both the supply and the demand for water.

SUMMARY

Based on our review, it is evident that significant climatic changes can result from major water diversions. They are measurable locally wherever the sizes of the water bodies are substantially increased or decreased, or large acreages of land are irrigated. The distance over which climate change will be felt may be relatively short except for the very largest water diversions. Temperature, humidity, cloud cover, and precipitation will all be affected.

A review of the precipitation patterns in central Saskatchewan before and after the construction of Lake Diefenbaker shows that, although significant changes in the distribution of precipitation have taken place, it is not possible to determine from available data sets if the lake played any role in them. The perceived changes of climate associated with a diversion cannot be considered without a good knowledge of the regional climate variability. There is evidence to show that for northern rivers, one of the greatest impacts resulting from water diversions may be the rerouting of stream flow into different oceans. To the extent that low saline waters influence the atmospheric heat and moisture budgets over the oceans, these diversions will have an impact on climate.

RECOMMENDATIONS

In order to gain a better understanding of the potential climatic impacts arising from water diversions, the following work should be carried out:

1) Models should be developed for use in assessing the impacts of medium and large scale reservoirs and irrigation projects in the context of different regional climates across Canada;
2) To authoritatively examine the climatic effects of a diversion it is important to make observations at judiciously placed sites both

before and after the construction of the diversion. Baseline climatic data collection programs should be initiated in areas where large scale water diversions are planned in the next 15 to 20 years;

3) The interdecadal variability of climate and particularly precipitation, should be studied through both historical and modelling research. Assessments of the needs for and impacts of waters diversions should be carried out within the context of a knowledge of changes in past climates and anticipated changes in future climates.
4) More research is needed to determine the role of river runoff in the global circulation. The requirements for this work are particularly important for the Arctic Basin.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Ms. Kristen Darlington, a geography student from the University of Waterloo, for her contributions to the analysis of the possible effects of Lake Diefenbaker on precipitation. In addition, they would like to thank Mr. Tom Moersch for his assistance in drafting most of the figures and to Messrs Law and Sheppard for making their climatological records available.

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SESSION D

INTERBASIN TRANSFER OF WATER:
WATER QUALITY AND ENVIRONMENTAL MODIFICATIONS

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Surface Water Division
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WATER CHEMISTRY CHANGES FOLLOWING DIVERSION, IMPOUNDMENT AND HYDROELECTRIC DEVELOPMENT IN NORTHERN MANITOBA

R.C. Playle[1], D.A. Williamson[2] and D.A. Duncan[2]

ABSTRACT

Water chemistry changes have been identified in northern Manitoba's aquatic environments affected by interbasin transfer of water and impoundment of rivers. The Churchill River diversion (CRD) and Lake Winnipeg regulation (LWR) were designed to enhance hydroelectric potential of the Nelson River and became operational in mid-1976. Statistical analyses of water chemistry data collected before and after mid-1976 from 10 sites along the Churchill, Burntwood and Nelson rivers indicated significant changes in a number of parameters. Conductivity decreased at all sites along the CRD route and increased at only one of four sites affected by LWR. Alkalinity decreased at four of five sites along the CRD route and was unchanged at the four upper Nelson River sites. Phosphorus concentrations increased at all sites affected by CRD except Split Lake where concentrations were unchanged. Turbidity and nitrogen concentrations tended to increase and decrease, respectively, throughout the region. Total inorganic carbon (TIC) decreased at three of the five sites along the CRD but increased at three of four sites affected by LWR. Split Lake, impacted by both CRD and LWR exhibited no change in TIC concentrations. Significant relationships were indicated between certain water quality parameters and flow; some relationships which existed prior to mid-1976 have altered or ceased to exist since that time. Major hydroelectric projects like CRD and LWR require extensive monitoring and analysis if potential environmental changes are to be accurately predicted.

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INTRODUCTION

Hydroelectric generating potential in the lower Nelson River, Manitoba, Canada, has been enhanced by the southward interbasin diversion of approximately 75% of the Churchill River (Newbury et al. 1984). The diversion of the Churchill River (CRD) was accomplished by firstly, constructing a dam across the northern outlet of Southern Indian Lake (SIL) at Missi Falls and secondly, excavating a channel across a southerly adjacent basin divide (Figure 1). The diverted Churchill River water enters the headwaters of the Rat River system through this channel, then flows into the Burntwood River and finally into the lower Nelson River at Split Lake. By mid-1976, SIL had risen to 3 m above the long-term mean and flow along the Burntwood River had increased approximately 9 times (Bodaly et al. 1984a). This diversion was also accompanied by regulation of Lake Winnipeg (LWR) discharges into the upper Nelson River. Lake Winnipeg levels are controlled for winter storage at Jenpeg generating station. Control channels include 2 Mile Channel between Lake Winnipeg and Playgreen Lake, and 8 Mile Channel between Playgreen Lake and Kiskittogisu Lake.

Lakes and rivers of the Churchill, Rat, and Burntwood systems flow through Precambrian Canadian Shield overlain by glaciolacustrine deposits. Lakes are usually riverine, relatively shallow, and turbid. High turbidity in the lakes is a result of lake morphology, strong winds and fine-grained shore and bottom sediments (Bodaly et al. 1984a). Conversely, the Nelson River system drains a large prairie sedimentary area before it enters the Canadian Shield. Consequently, the total ion concentration and suspended sediment load of the Nelson River are higher than the Churchill River (Bodaly et al. 1984a). The climate is continental subarctic and the vegetation is boreal. Lakes are generally isothermal during the ice-free season (about 5 months) and have oxygen levels near saturation (Bodaly et al. 1984a).

Further description of the area's lakes, geology and details concerning hydroelectric development of the Churchill and Nelson rivers can be found in Bodaly et al. (1984a), Newbury et al. (1984), and Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB 1975).

METHODS

Water chemistry data were collected at sites in the CRD and LWR regions from approximately 1972 to 1984. Samples were usually collected 6 to 8 times per year, at 3 to 4 equally spaced intervals during the ice-free and ice-covered periods. All samples were collected from 0.5 to 1.0 m below the water's surface. Samples were submitted to the W.M. Ward Technical Services Laboratory, Winnipeg, Manitoba for analyses. Sample preservation and analytical methods were in accordance with Sorba et al. (1980). Such data generated by the Manitoba Department of Environment and Workplace Safety and Health were supplemented with compatible data

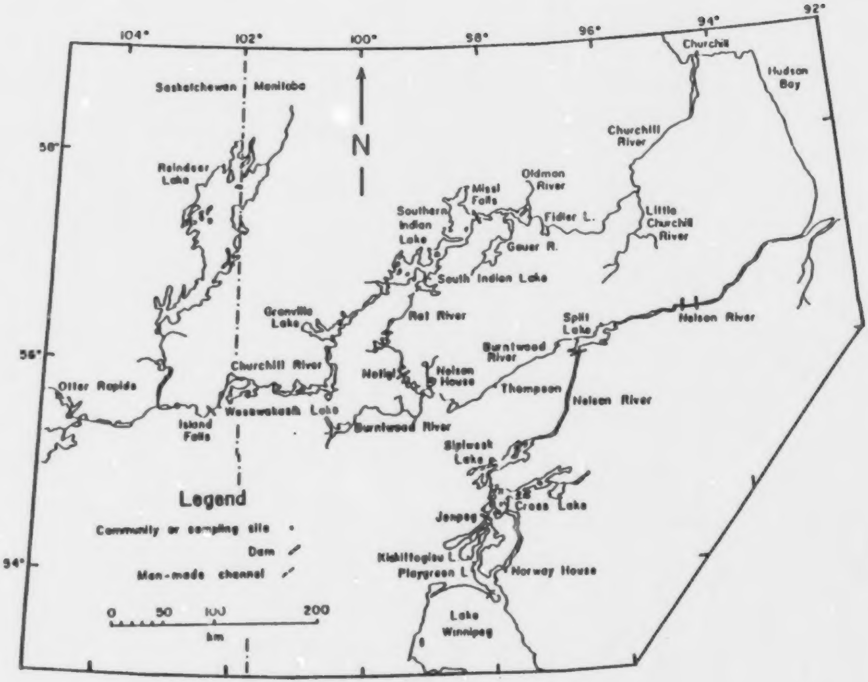

104°
102°
100°
98°
96°
94°
92°
58°
56°
54°
N
Saskatchewan
Manitoba
Churchill
Hudson Bay
Churchill River
Reindeer Lake
Oldmon River
Missi Falls
Southern Indian Lake
Fidler L.
Little Churchill River
Gauer R.
South Indian Lake
Granville Lake
Rat River
Split Lake
Nelson River
Burntwood River
Churchill River
Otter Rapids
Nelson House
Notigi
Thompson
Nelson River
Wasawakasik Lake
Island Falls
Burntwood River
Sipiwesk Lake
Legend
Community or sampling site
Dam
Man-made channel
0
50
100
200
km
Cross Lake
Jenpeg
Kiskittogisu L.
Playgreen L.
Norway House
Lake Winnipeg

Figure 1: The Churchill River diversion and Lake Winnipeg regulation project area, Manitoba, Canada.

collected from the same sites by the Canada Departments of Environment and Fisheries and Oceans. Data were considered compatible if the field collection, sample preservation, analytical methods and limits of quantitation were similar.

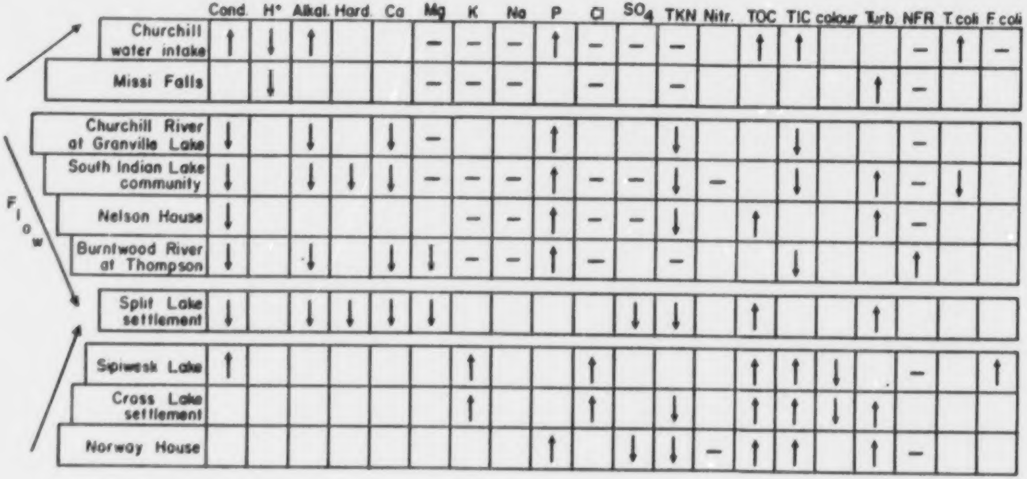
Several criteria were used to select specific variables for statistical analyses. These included the following: (a) Variables were excluded when analytical methods were significantly altered during the comparison period (e.g. most trace metals including iron, copper and lead). (b) At least 2 years of data from before and after mid-1976 were required for statistical analyses, although coliform bacteria were an exception to this criteria. Mid-1976 was considered the period that most CRD and LWR projects became operative. (c) The data had to be approximately equally spaced in time (e.g. all samples could not have been collected during winter only). (d) Variables were excluded if more that 20% of the data were recorded as less than the analytical limit of quantitation. Data occasionally recorded as less than this limit were assigned values one-half the quantitation limit. (e) Occasional data that were apparent outliers, such as a misplaced decimal, and which could not be verified were omitted.

Twenty water quality parameters were selected using the above criteria. Student's t-test was used to statistically compare pre-development data with post-development data. A two-tailed test of significance was utilized with $\alpha=0.05$. Bacterial data were log $(x+1)$ transformed prior to statistical analyses. Degrees of freedom were calculated assuming that the variances were unequal (Welch's method; NWA STATPAK 1984). Parameters at two sites were regressed against flow data to determine the existence of linear relationships. Statistical analyses were conducted on an IBM personal computer utilizing the NWA STATPAK (1984; 1986) software package.

RESULTS AND DISCUSSION

An overview of statistically significant regional water chemistry changes is illustrated in Figure 2. Statistical analysis can be used to infer cause and effect, where treatment (project) replication, interspersion, or randomization, and controls are included in the experimental design (Hurlbert 1984). These design parameters are seldom available for analyzing impacts of large scale hydroelectric projects. However, project effects were separated from natural temporal variation and upstream anthropogenic alterations through comparison with an upstream control or reference site (Churchill River at Granville Lake). Statistically significant changes were compared with predictions made by the LWCNRSB (1975).

Figure 2: Summary of statistically significant regional water chemistry changes. The arrows on the left margin indicate the direction of water flow. The arrows within the figure indicate the direction of water chemistry change. The symbol (-)indicates insufficient data for analysis.



	Cond.	H+	Alkal.	Hard.	Ca	Mg	K	Na	P	Cl	SO_4	TKN	Nitr.	TOC	TIC	colour	Turb	NFR	T.coli	F.coli
Churchill water intake	↑	↓	↑			–	–	–	↑	–	–	–		↑	↑			–	↑	–
Missi Falls		↓				–	–	–		–		–					↑	–		
Churchill River at Granville Lake	↓		↓		↓	–			↑			↓			↓			–		
South Indian Lake community	↓		↓	↓	↓	–	–	–	↑	–	–	↓	–		↓		↑	–	↓	
Nelson House	↓						–	–	↑	–	–	↓		↑			↑	–		
Burntwood River at Thompson	↓		↓		↓	↓	–	–	↑	–		–			↓			↑		
Split Lake settlement	↓		↓	↓	↓	↓					↓	↓		↑			↑			
Sipiwesk Lake	↑						↑			↑				↑	↑	↓		–		↑
Cross Lake settlement							↑			↑		↓		↑	↑	↓	↑			
Norway House									↑		↓	↓	–	↑	↑		↑	–		

Upstream Reference Sites

Conductivity, alkalinity, calcium, total Kjeldhal nitrogen (TKN), and total inorganic carbon decreased at the reference site while total phosphorus (total P) increased (Figure 2 and Table 1). Similar changes in water chemistry were observed at Otter Rapids and Wasawakasik Lake, located on the Churchill River upstream of Granville Lake (data not presented). In addition, statistically significant decreases in concentrations of K, Na, Cl, and SO_4 at Wasawakasik Lake were observed. Such changes likely resulted from either variations in the patterns and quality of water released from Reindeer Reservoir into the Churchill River, variations in natural events such as precipitation or a combination of these factors. For example, increased precipitation resulting in above-average Churchill River discharge in 1974 to 1977 (Newbury et al. 1984) could have resulted in decreased conductivity and alkalinity at all upstream sites. Only 5 water quality parameters exhibited statistically significant linear relationships with the natural logarithm (ln) of Churchill River flows. Total P, Mg and total organic carbon (TOC) had inverse relationships while turbidity and H^+ concentration were positively correlated with ln flow (Table 2). Upstream regulation of discharge and a damping effect of lakes may have reduced or masked some relationships between water quality and flows. Further, TKN decreased significantly at all sites except Sipiwesk Lake. Systematic analytical bias or a natural decreasing trend could have caused the apparent decreases in TKN. Consequently, TKN will not be discussed further. These statistically significant changes make interpretation of water chemistry changes at sites affected by the CRD and LWR more complex.

Churchill River Diversion Route

Water chemistry in SIL near the community of South Indian Lake changed in a similar manner as was observed at Granville Lake. Additionally, statistically significant decreases in hardness and total coliform bacteria, and an increase in turbidity were observed.

Most water chemistry changes were a result of the increased flow of Churchill River water past the community of South Indian Lake. Following CRD, the residence time of South Bay, SIL (just south of the community of South Indian Lake), decreased from 4 years to 11 days (Bodaly et al. 1984a). Prior to CRD, conductivity, alkalinity, hardness, and Ca were higher at SIL than at Granville Lake and at Missi Falls. After the CRD, water chemistry near the community of South Indian Lake was very similar to the Churchill River at Granville Lake, as predicted by the LWCNRSB (1975). Mean total coliform bacteria decreased near the community, likely because of the increased dilution due to the increased flow. Fecal coliform densities also decreased, but the decrease was not statistically significant. The LWCNRSB (1975) had predicted that the increased flow past the South Indian Lake community would reduce local lakeshore coliform densities.

Table 1. Mean water chemistry values for before and after mid-76, from sites along the Churchill, Rat, Burntwood and Nelson river systems. Rejection of the null hypothesis that water chemistry did not change in the two periods of comparison is denoted by an *.

Location		H^+ $\times 10^{-6}$ M/L	Cond. µS/cm	Hard. mg/L	Alkal. mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	Cl mg/L	SO_4 mg/L
Churchill River	x_1	2.84	118*	46	46*	13.5*	-	1.3	3.3	1.3	4
at Granville Lake	x_2	3.52	78	41	34	8.9		1.2	3.0	1.0	6
South Indian Lake	x_1	1.85	128*	58*	58*	16.0*	a	a	a	a	a
Community	x_2	1.77	84	37	40	10.6					
Nelson House	x_1	2.18	165*	80	76	23.2	6	a	a	a	a
	x_2	2.47	142	76	71	20.9	5				
Burntwood River	x_1	1.87	147*	71	68*	21.3*	6*	a	a	a	4
at Thompson	x_2	1.65	116	68	58	17.9	5				5
Split Lake	x_1	1.07	290*	121*	104*	29.2*	11*	2.4	15	16	25*
Settlement	x_2	0.94	235	106	83	25.2	9	2.3	13	14	16
Sipiwesk Lake	x_1	1.00	302*	120	103	29.0	11	2.5*	17	18	26
	x_2	0.86	323	124	106	31.9	12	3.0	19	21	26
Cross Lake	x_1	1.61	303	120	101	29.2	11	2.6*	16	17*	28
Settlement	x_2	1.17	320	119	103	30.5	12	3.2	19	23	27
Norway House	x_1	1.13	296	114	99	27.8	11	2.3	16	16	25*
	x_2	1.03	292	106	96	28.3	11	2.5	15	18	21
Churchill	x_1	1.98*	118*	51	51*	15	a	a	a	a	a
Water Intake	x_2	1.15	130	57	60	16					
Missi Falls	x_1	2.40*	116	44	49	12.4	a	a	a	a	4
	x_2	1.74	105	44	49	13.0					4

x_1 = mean of data to June 30, 1976.
x_2 = mean of data from July 1, 1976.
* = $\bar{x}_1 \neq \bar{x}_2$; P≤0.05
- = insufficient data.
a = too many data < detection limit.

Table 1. Continued

Location		NFR mg/L	Turb. NTU	Colour Units	Total P µg/L	TKN mg/L	NO_3 NO_2 mg/L	TOC mg/L	TIC mg/L	T. Coli MPN/100ml.	F. Coli MPN/100 ml.
Churchill River at Granville Lake	$\bar{x}_1$	-	4.3	12	15*	0.6*	0.06	8	9*	7	0.4
	$\bar{x}_2$		4.9	16	22	0.4	0.05	10	8	3	0.4
South Indian Lake Community	$\bar{x}_1$	a	3.7*	11	17*	0.6*	a	9	13*	10*	1.0
	$\bar{x}_2$		8.0	11	28	0.3		10	8	3	0.3
Nelson House	$\bar{x}_1$	a	2.7*	27	25*	0.7*	0.09	12*	16	3	0.1
	$\bar{x}_2$		4.7	22	39	0.5	0.08	14	16	2	0.1
Burntwood River at Thompson	$\bar{x}_1$	11.4*	21.8	50	35*	-	0.11	13.5	14.3*	22	1.5
	$\bar{x}_2$	19.7	18.6	41	58		0.12	13.0	13.0	19	3.2
Split Lake Settlement	$\bar{x}_1$	11	7.2*	21	57	0.6*	0.08	10*	21	7	0.8
	$\bar{x}_2$	11	13.6	18	41	0.4	0.07	13	19	12	1.6
Sipiwesk Lake	$\bar{x}_1$	a	8.3	15*	33	0.6	0.06	9.4	20.6*	1	0.0*
	$\bar{x}_2$		8.6	9	32	0.4	0.07	12.8	24.3	2	0.2
Cross Lake Settlement	$\bar{x}_1$	10	5.7*	16*	35	0.6*	0.13	10*	20*	14	0.5
	$\bar{x}_2$	8	8.4	11	35	0.5	0.06	14	24	5	0.7
Norway House	$\bar{x}_1$	a	5.3*	16	25*	0.7*	a	11*	19*	14	0.9
	$\bar{x}_2$		7.2	15	33	0.5		15	22	9	1.0
Churchill Water Intake	$\bar{x}_1$	a	3.4	18	17*	-	0.24	9*	11*	2*	
	$\bar{x}_2$		5.8	16	35		0.12	12	14	28	
Missi Falls	$\bar{x}_1$	a	1.9*	11	18	-	0.06	9	10	2	0.3
	$\bar{x}_2$		6.0	9	20		0.05	8	11	3	0.2

$\bar{x}_1$ = mean of data to June 30, 1976.
$\bar{x}_2$ = mean of data from July 1, 1976.
* = $\bar{x}_1 \neq \bar{x}_2$; $P \leq 0.05$
- = insufficient data.
a = too many data < detection limit.

Table 2. Correlation coefficients (r) and sample size (n) for significant linear regressions (α=0.05) of water quality parameters against in flows.

Location		Cond. µS/cm	H^+ x10^{-8}M/L	Alkal. mg/L	Hard. mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	Total P µg/L	Cl mg/L
Churchill River	$r_1(n_1)$									-.431(23)	
at Granville Lake	$r_2(n_2)$		.383(39)				-.572(17)			-.315(39)	
Burntwood River	$r_1(n_1)$	-.705(89)		-.672(90)	-.743(85)	-.549(85)		-.220(90)	-.707(87)	.319(43)	-.571(88)
at Thompson	$r_2(n_2)$	-.286(53)	-.385(54)	-.586(37)		-.499(37)					.527(15)

Table 2: continued

Location		TKN mg/L	TOC mg/L	TIC mg/L	Colour units	Turb. NTU	NFR mg/L
Churchill River	$r_1(n_1)$					.421(28)	
at Granville Lake	$r_2(n_2)$		-.501(18)				
Burntwood River	$r_1(n_1)$			-.767(42)	.498(89)	.433(88)	
at Thompson	$r_2(n_2)$	-.293(47)	-.441(33)	-.475(33)	.535(15)	.441(30)	.535(46)

r_1 = correlation coefficient for pre-1976 data
n_1 = sample size for pre-1976 data
r_2 = correlation coefficient for post-1976 data
n_2 = sample size for post-1976 data

The increase in turbidity at SIL was caused by flooding of SIL and subsequent erosion of fine-grained tills and lacustrine soils in permafrost (Bodaly et al. 1984a; Newbury and McCullough 1984). Newbury and McCullough (1984) suggested that high turbidity in SIL will persist for about 35 years, the minimum estimated period for bank stabilization. This estimate appears reasonable since after 43 years, erosion of glaciolacustrine shores is still a problem within the Long Lake diversion in northwestern Ontario (Day et al. 1982). Although flooding of SIL was expected to increase total P, upstream increases in total P confounded the rigorous statistical testing of this prediction. Nevertheless, the magnitude of total P increase at SIL was greater than that observed at Granville Lake: post-CRD increase in total P at SIL was 65% while total P increased only 47% at Granville Lake. Such differences suggest that some total P was released from flooded land. The predicted increase in nutrients was not expected to increase biological activity in SIL principally because light extinction due to increased turbidity was expected to ameliorate effects of additional nutrients (LWCNRSB 1975).

Water chemistry near the community of Nelson House was relatively stable throughout the study period, likely a consequence of its location off the main flow of the diversion. Statistically significant increases were observed for total P, TOC and turbidity. Water levels at Nelson House increased by about 3.6 m after the diversion (Bodaly et al. 1984b). Consequently, flooding was likely responsible for increases in TOC, turbidity and in part, for the observed increase in total P. Previously discussed increases in total P at sites upstream of the CRD can likely account for the majority of observed total P increase at Nelson House. However, the magnitude of the increase (from 25 to 39 µg/L) suggests that release of total P from newly flooded land was responsible for some of the increase. A statistically significant decrease was observed for conductivity at Nelson House. Conductivity decreased 14% from 165 to 142 µS/cm. This decrease was slightly less than the 34% decrease observed at the upstream reference site and at SIL.

Numerous water chemistry changes were observed in the Burntwood River at Thompson. Statistically significant decreases were observed for conductivity, alkalinity, Ca, Mg, and TIC. Diversion of softer Churchill River water down the Burntwood River was likely responsible for these changes. Concentrations for these parameters at Thompson were similar to concentrations measured on the Churchill River at Granville Lake. Total P increased at Thompson, likely due to both increases in the upstream diverted water of the Churchill River combined with total P released from eroded river bed and shoreline materials. Non-filterable residues (NFR) also evidenced a statistically significant increase from 11.4 to 19.7 mg/L. This likely resulted from the increased available energy associated with the approximate 9 times increase in water discharge. However, changes were not observed for turbidity at this sampling site. The reason for this contradiction is not known, although it is probably related to the differing sensitivities of the respective analytical procedures to detect increases of small magnitude. A similar phenomenon was described by Likens et al. (1970) within the Hubbard Brook

Experimental Watershed. Suspended sediment concentrations increased in a stream following clear-cutting of the surrounding forest while turbidity remained stable. Noteworthy is the fact that although measured NFR concentrations increased by only a small magnitude and turbidity did not statistically significantly increase, the actual suspended sediment load being transported greatly increased as a direct consequence of the increased discharge rate.

Numerous parameters were linearly related to the ln of Burntwood River flows at Thompson. Conductivity, alkalinity, Ca, Cl and TIC all exhibited inverse relationships with flow both before and after 1976 (Table 2). Similarly, turbidity and colour were positively correlated with ln flow both before and after the diversion. Hence, CRD did not change the inherent nature of these relationships. Total P, hardness, K and Na exhibited statistically significant linear relationships with ln flow prior to CRD but not after CRD. Conversely, H^+, TOC and NFR had significant linear relationships with ln flow after CRD but not before. Noteworthy is the fact that only three parameters (Mg, SO_4 and NO_3-NO_2) were not linearly related to ln flow during either period, thus emphasizing the potential importance of discharge to water quality in a riverine system.

Split Lake is located at the junction of the Burntwood and Nelson rivers, and can be affected by changes in either river system. Prior to the diversion, the water chemistry of Split Lake was dominated by the upper Nelson River, with higher conductivity, alkalinity, hardness, and major ions than the Burntwood River. Following the CRD, statistically significant decreases were observed in conductivity, alkalinity, hardness, Ca, Mg, and SO_4. These changes were similar to those observed at other upstream sites on the CRD route.

Mean conductivity at Split Lake decreased from 290 to 235 µS/cm as a result of the increased flow of softer, Churchill River water. Hardness (as $CaCO_3$) decreased from 121 to 106 mg/L. Further, the LWCNRSB (1975) had predicted that Ca would decrease from 30 to 27 mg/L; the actual decrease was from 29 to 25 mg/L. A statistically significant increase was observed in TOC from 10 to 13 mg/L. This followed a trend similar to that observed on the upper Nelson River. Turbidity at Split Lake increased after the CRD, likely because of increased flow of more turbid water along the Burntwood River. High turbidities, however, were recorded occasionally at Split Lake and other upper Nelson River sites in 1972. Unfortunately, prior to April, 1974, turbidity at Split Lake was measured in Jackson Turbidity Units, rather than Nephelometric Turbidity Units, thus making statistical comparison with later turbidity measurements invalid. However, the data do suggest that variations in turbidity at Split Lake can be erratic and perhaps cyclic.

Upper Nelson River Sites

Lake Winnipeg regulation had the general effect of altering the natural seasonal periodicity of discharges, altering the route of the major portion of discharges through the Lake Winnipeg outlet lakes area and altering historical minimum and maximum lake levels. Such perturbations resulted in a number of subtle, but statistically significant water chemistry changes.

The community of Norway House is located on the east arm of the upper Nelson River. Comparisons of data collected near the community before and after mid-1976 yielded statistically significant increases in total P, TOC, TIC, and turbidity, and decreases in SO_4. Similar changes were observed further downstream at both Cross and Sipiwesk lakes. Statistically significant increases were observed for K, Cl, TOC, TIC and turbidity at Cross Lake, while colour decreased. Statistically significant increases were observed for conductivity, K, Cl, TOC, TIC and fecal coliform bacteria at Sipiwesk Lake and were accompanied by a marginally significant decrease in colour.

Some of these water chemistry changes can be related to LWR. Shoreline degradation was expected to occur at Cross Lake following LWR (Dickson 1975). Total organic carbon and TIC increased from approximately 10 to 14 mg/L at all three upper Nelson River sites. These changes likely occurred due to shoreline erosion or channel construction exposing new soils to erosion. Similarly, total P and turbidity increased at Norway House possibly resulting from construction of 2 Mile Channel. This channel both exposed new soils to erosional processes and created the necessary pathway to allow sediment transport into Playgreen Lake from Lake Winnipeg during periods of strong south winds. This effect was predicted by the LWCNRSB (1975). Turbidity increased at Cross Lake, probably because of decreased water levels (reduced by 1.7 m). Entrainment of bottom sediments by wind action was probably the causitive agent (Bodaly et al. 1984a). However, similar to Split Lake, high turbidities have been recorded from this area prior to LWR. Occasionally high historical turbidities combined with the relatively small increase in turbidity require cautious interpretation of Norway House and Cross Lake turbidity data.

Causes of observed changes for other parameters (i.e. K and Cl at Cross and Sipiwesk lakes) are not known, but may also be related to erosion. Causes of decreases in colour at the two sites are also not known, but appear, intuitively, to be unrelated to Lake Winnipeg regulation. Fecal coliform bacteria apparently increased in Sipiwesk Lake, but the significance of this increase was relatively low ($P=0.025$). The apparent increase therefore, is probably an artifact of the zero standard deviation of the data from before mid-1976.

Lower Churchill River

Water chemistry in the lower Churchill River was expected to change following diversion due to greater influence of local tributaries. The proportion of discharge within the lower Churchill River attributed to local tributaries changed from approximately 8% prior to diversion to approximately 37% following diversion (LWCNRSB 1975). Generally, these tributaries were less acidic, more highly coloured and contained greater concentrations of dissolved minerals and organic materials than the lower Churchill River prior to diversion. Consequently, conductivity, Ca, Mg and total dissolved solids were expected to increase after the diversion, while Na concentrations and total P loading were expected to decrease.

Following the diversion, H^+ concentration decreased and turbidity increased at Missi Falls. Other parameters remained stable. Hydrogen ion concentration decreased due to the increased influence of local tributaries. Turbidity increased at Missi Falls due to erosion in SIL. Phosphorus concentrations remained stable at Missi Falls, in contrast with increases observed at the upstream reference site. This tends to support the prediction of the LWCNRSB (1975) that P concentrations would decrease at Missi Falls because of the diversion of nutrient-rich Churchill River water (i.e. P decreases at Missi Falls were countered by the general P increase observed at upstream sites).

A number of changes in water chemistry occurred at the community of Churchill's water treatment plant intake. These included increases in conductivity, alkalinity, total P, TOC, TIC and total coliform bacteria and a decrease in H^+ concentration. In general these changes resulted from the increased influence of local waters on lower Churchill River chemistry. Limited data were available for only three of these tributaries, namely the Gauer, Oldman, and Little Churchill rivers. However, post-diversion P concentration at the Churchill water intake was higher than the pooled mean of the tributaries. Total P concentrations in the lower Churchill River increased from 17 to 35 µg/L while the pooled tributary mean was 22 µg/L. Other tributaries to the lower Churchill River may have supplied the additional phosphorus or phosphorus may have been eroded from newly exposed river banks (Ingram et al. 1985) in the lower Churchill River.

In a similar analysis of data from Fidler Lake, below Missi Falls, Guilbault et al. (1979) observed increases in hardness, Ca, total P, and TIC. All such changes can be explained by the increased importance of local drainage to lower Churchill River chemistry after the diversion. Guilbault et al. (1979) also observed an increase in colour and turbidity at Fidler Lake. Colour increased from 9.9 to 18.6 relative units, while turbidity increased from 2.1 to 10.0 JTU. The mean colour of the Gauer, Oldman, and Little Churchill rivers was 27 relative colour units, thus explaining the increased colour in the lower Churchill River following diversion. Turbidity likely increased because of increased turbidity in SIL.

CONCLUSIONS

Some water chemistry changes along the Churchill, Burntwood, and Nelson rivers can reasonably be attributed to the Churchill River diversion and Lake Winnipeg regulation, in spite of analytical method changes and other changes unrelated to these projects. Some water chemistry parameters along the diversion path changed because of flooding, erosion and increased flows of softer Churchill River water. Water chemistry at Split Lake was affected by the increased flow of turbid, softer water down the Burntwood River, and was also affected by changes in the upper Nelson River. Increases in turbidity, TOC and TIC were observed at sampling sites located on the upper Nelson River. These changes may have been a result of LWR. Water chemistry in the lower Churchill River changed because of increased turbidity from flooding and erosion in SIL and because local drainage had more influence on water chemistry once most of the Churchill River flow was diverted southward.

In general, predictions of water chemistry changes caused by the hydroelectric projects were good, especially those predictions related to changes in water flow. This is in marked contrast with biological predictions for SIL, which became less reliable as trophic level increased (Hecky et al. 1984). Some predictions, such as oxygen depletion in lakes resulting from decomposing vegetation, could not be assessed because of too few data.

Hydroelectric development is often labelled non-polluting, but it can have large effects on the environment (Efford 1975), some of which are not well known for northern areas. A parameter such as conductivity at Split Lake will continue to be a relatively simple function of mixing two volumes of water of different conductivities, but turbidity at Missi Falls or SIL will be more difficult to predict. The Lake Winnipeg, Churchill and Nelson Rivers Study Board collected valuable background information for evaluating consequences of the CRD (Hecky et al. 1984). Continued monitoring, analysis and interpretation of water chemistry data is necessary in order to better understand the complex impacts of hydroelectric development in northern Canada.

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INTERBASIN TRANSFER: IMPACTS ON WATER QUALITY

V. Remenda[1] and E. Davis[2]

ABSTRACT

Deterioration of the quality of impounded water due to an inflow of groundwater is known to occur is some surface reservoirs in Saskatchewan. A methodology to aid in reservoir site selection for the maintenance of high quality impounded waters must be developed and used to investigate the cause of water quality deterioration in existing and potential reservoirs. Two potential reservoir sites, the Anerley Channel and Tramping Lake, and two existing Interbasin Transfers, the Qu'Appelle Diversion and the Saskatoon Southeast Water Supply System are identified and discussed in terms of water quality deterioration due to groundwater discharge.

To the goal of developing a methodology, a study-region that encompasess the Blackstrap Reservoir was established. Exisitng information was utilized together with field and laboratory data to establish the stratigraphy, and the regional and local groundwater framework.By defining the geology, hydrochemistry and the surface and ground water hydrology, the interaction between the reservoir and the physical envionment can be predicted.

Ellucidation and refinement of this methodology may provide a scientific basis for reservoir site selection for the maintenance of water quality.

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INTRODUCTION

As available water supplies diminish in quantity and quality, greater value will be placed on fresh water. The diversion and transfer of fresh water appears to be an inevitable solution to this problem of a diminishing supply divided among a growing number of users. These transfers may, however, have a very real and irreversible impact on the quality of the transported water. Two equally vital themes need to be addressed:

- The need for water quantity to relieve water demands of a province, and
- The need to safeguard the impounded water against deterioration so that water resources remain of acceptable and usable quality.

Four sites are discussed in terms of a possible cause of water quality deterioration by an inflow of highly mineralized groundwater. Two proposed reservoir sites serve to illustrate the potential impact of the physical environment on water quality. Two existing interbasin transfers where water quality is subject to deterioration due to groundwater discharge are identified. The need for a methodology for reservoir site selection for the maintenance of impounded water quality is demonstrated.

The groundwaters of the Prairies tend to be highly mineralized. In this semi-arid region where evaporation often exceeds precipitation, there is a propensity for a greater concentration of minerals in the groundwater (Hem, 1970). The geologically young sediments of the Prairies provide an abundance of minerals for leaching. Discharge waters are generally more mineralized than recharge waters (Freeze and Cherry, 1979).

Many obvious locations for water storage and diversion, for example meltwater channels, are often areas of groundwater discharge. Discharge of highly mineralized groundwater from surrounding geologic strata into a reservoir has been identified by several authors as the cause of water quality deterioration (Weiterman, 1987; Davis and Sauer, 1983; McCrory, 1983).

A scientific basis for reservoir site selection for the maintenance of impounded water quality is required. A methodology that employs exisiting information, coupled with a field investigation would provide a simple and cost-effective means to understand the interaction of a reservoir and its environment. Saskatchewan has a vast data base of surface and sub-surface information that is readily available from government sources such as Saskatchewan Water Corporation water well driller's logs, Saskatchewan Research Council bedrock maps, surficial geology maps and well and surface water quality files, and Saskatchewan Institute of Pedology soils maps.

The effects of groundwater discharge into a basin and the quality of the stored water may be anticipated through an understanding of the physical environment of that basin before the storage or transport reservoirs are developed.

PROPOSED DIVERSION TO THE LAKES OF THE ANERLEY CHANNEL

A preliminary investigation has been initiated of a possible diversion of water from Lake Diefenbaker through Coteau Creek to the lakes comprising the Anerley Channel (Figure 1). This scheme is envisioned as providing water for irrigation as well as a more reliable supply for domestic use.

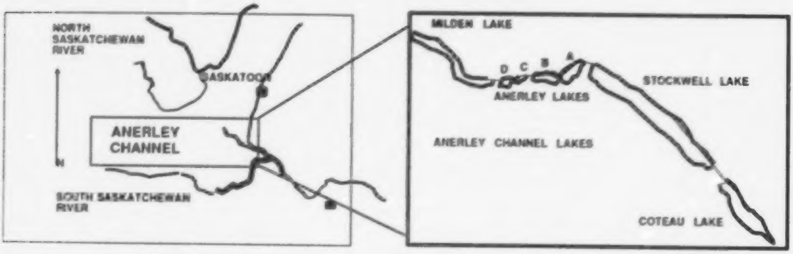


Figure 1: Schematic Diagram of the Location of the Anerley Channel.

The Anerley Channel consists of a series of seven lakes that lie to the west of Lake Diefenbaker. The Channel is approximately one kilometre wide and 20 kilometres long and the bottom elevation of the lakes is approximately 1900 feet above sea level. The valley walls are very steep and high, rising to about 2050 feet on the south side and about 2000 feet on the north side of the channel. The Channel divides the Missouri Coteau Upland to the south and the Anerly Plain to the north (Ellis et al., 1970).

The Anerley Channel was likely formed during the Wisconsinan deglaciation as a ice-marginal or sub-glacial spillway. The flowing meltwater cut through the glacial drift and possibly bedrock, and subsequently deposited about 100 feet of stratified drift in the channel. The stratgraphy is very simple: the Judith River Formation, composed of sand, silt and clay, is overlain by the Bearpaw Formation, composed of silt and clay, which is in turn overlain by glacial drift of variable composition.

There is evidence of groundwater discharge in the channel bottom. Mitchell et al. (1944) mapped the soils in the bottom of the Anerley Channel as "alkali".

Field observations of the Anerley Channel show that the lakes have saline perimeters and vegetation such as *salicornia rubra* that is associated with saline conditions. Salt crystal aggregates are present along the shorelines of lakes containing water. Stockwell and Coteau Lakes appeared to be dry in October 1987, and the surface sediments of both were cracked. Salt crystals were present in the cracks.

Water samples were obtained from the two lakes that could be sampled. The water samples were tested at the Environmental Engineering Laboratory, University of Saskatchewan for major ions. The Total

Dissolved Solids (TDS) of the water samples was approximately 20,000 mg/L, with magnesium and sulfate dominating the ion chemistry (Table 1).

Table 1:Major Ion Analyses of two of the Anerley Lakes.

Anerley (A)			
cation		anion	
Ca^{2+}	282.	CO_3^{2-}	83.
Mg^{2+}	2472.	T.Alk	341.
Na^+	1744.	Cl^-	846.
K^+	249.	NO_3^-	<0.02
Fe	0.15	SO_4^{2-}	13,047.
Anerley (B)			
cation		anion	
Ca^{2+}	438.	CO_3^{2-}	92.
Mg^{2+}	4447.	T.Alk	521.
Na^+	3098.	Cl^-	1559.
K^+	392.	NO_3^-	<0.02
Fe	0.65	SO_4^{2-}	23,178.

(expressed in mg/L of the ion except T.Alk which is in mg/L of CaCO3).

This preliminary investigation illustrates the potential for the deterioration of diverted water due to an inflow of highly minerlized groundwater. To divert water through this channel before investigating the physical environment could result in a serious degradation of water quality for all time in the future.

DIVERSION FROM THE NORTH SASK.RIVER THROUGH TRAMPING LAKE TO THE SOUTH SASK.RIVER

Recently a plan has been proposed to pump water from the North Saskatchewan River and distribute it in the dry west-central portion of the province (Figure 2). Tramping Lake has been identified as a possible storage and transport reservoir because of its large size and long north-south orientation.

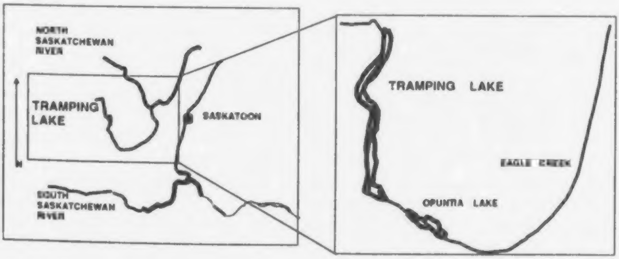


Figure 2: Schematic Diagram of the Location of Tramping Lake.

Tramping Lake Valley originated as a meltwater channel (Christiansen, 1979) during the retreat of the Wisconsinan glacier. The valley was eroded through the drift some 26 meters into the Judith River Formation. Approximately 20 meters of alluvium was subsequently deposited in the channel. The investigation of a spectacular foundation failure of a highway grade crossing the lake has provided the stratigraphic framework of Tramping Lake.

A series of piezometers set at different levels in the Tramping Lake Alluvium indicate an increasing hydraulic head with depth and thus a potential for an upward flow of water into the lake bottom. The water level in the lake is presently just below the top of the Judith River Formation.

The quality of the water obtained from the piezometers deteriorates rapidly as it approaches the lake bottom from below. The TDS in the Judith River Formation, 88 meters below the lake surface, is 1160 mg/L, 23 meters below the lake surface it is 3920 mg/L, and the lake water contains 12,380 mg/L of TDS. The concentration of minerals in the water of Tramping Lake corresponds to about a half million tonnes of salts.

Core samples of the alluvium from the lake bottom indicated a high concentration of crystals of salt in the bottom muds. The concentration of sodium ions and sulfate ions in the bottom muds indicate about 75 million tonnes of salts in that location.

This vast reservoir of minerals in the lake precludes use of Tramping Lake as a transportation and storage reservoir. Any fresh water entering the lake would be degraded in quality in proportion to the quality and quantity of discharge up into the lake bottom.

QU'APPELLE DIVERSION

A flow of 2 to 10 m^3/sec is diverted from Lake Diefenbaker to the Qu'Appelle River (Figure 3). The purpose of this diversion was to flush out the notoriously poor water of Buffalo Pound Lake and thereby improve the quality of the raw water supply of the cities of Regina and Moose Jaw. An additional objective of this diversion was to stabilize the water levels and also the water quality of the Fishing Lakes. Neither of these objectives has been realized.

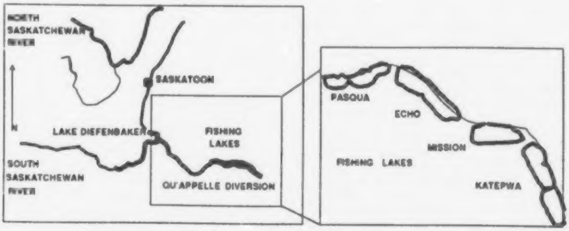


Figure 3: Schematic Diagram of the Location of the Qu'Appelle Diversion and the Fishing Lakes.

The valley of the Qu'Appelle River is a former meltwater channel. When the spillway intersected the preglacial Hatfield Valley Aquifer, very high velocity gradients associated with massive upflows of water from that aquifer carried the alluvial material out of the immediate area leaving a large deep lake. The effect of the vertical and horizontal currents was overcome by delta formations which separated the single post glacial Fishing Lake into the present four Fishing Lakes (Christiansen et al., 1977).

A cross-section of Katepwa Lake (Figure 4) indicates that there is still a major contribution of groundwater into the Fishing Lakes which dictates, in part, the Lake levels and the chemical constituents of the lakes (Schreiner and Maathius, 1982).

The mineral salt content of the Hatfield Valley Aquifer water is from 8 to 9 times higher than that of the South Saskatchewan River. Any storage of South Saskatchewan River water in the Fishing Lakes would result in a marked deterioration in proportion to the relative contributions from the river and from the Hatfield Valley Aquifer.

The Fishing Lakes are notorious for their massive and obnoxious algal blooms. These algal blooms have been documented as early as 1857 which indicates that they are not merely a function of agricultural activity in the valley or of the sewage effluent from surrounding communities.

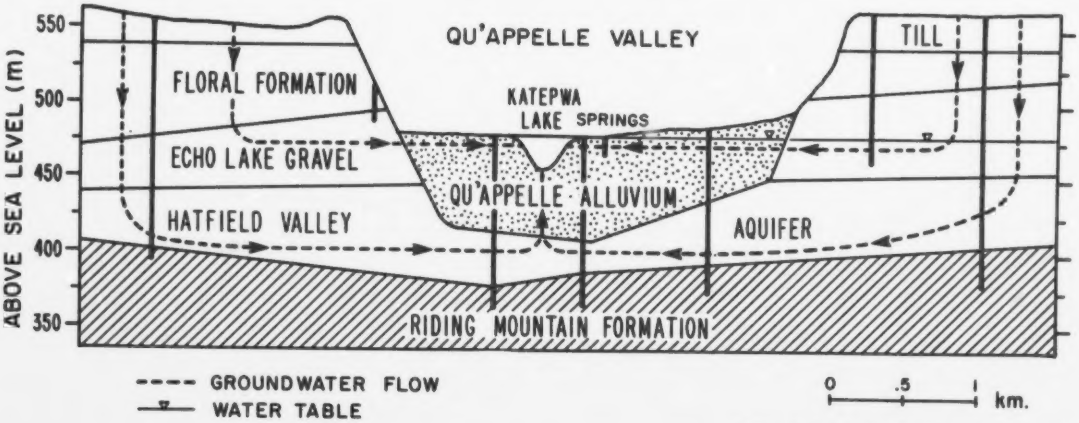
Phosphorus levels (as PO_4) have been monitored in the Fishing Lakes. Table 2 gives both TDS and PO_4 values for samples collected in both 1986 and 1987.

Table 2: Phosphate Content of Water in Qu'Appelle River Chain

location	TDS content		PO_4 content	
	1986	1987	1986	1987
Lake Diefenbaker				
Gardiner Dam	246	274	<0.01	0.018
Qu'Appelle Dam	267	259	<0.01	0.022
Buffalo Pound Lake				
Causeway	308	285	0.04	0.06
Treatment Plant Intake	316	333	0.06	0.08
Lake outlet	339	333	0.12	0.20
Qu'Appelle River				
Lumsden Bridge	877	461	0.12	0.42
Exit from Pasqua Lake	1223	1244	0.72	0.58
Exit from Echo Lake	1209	1256	0.52	0.58
Exit from Mission Lake	1155	1174	0.78	0.90
Exit from Katepwa Lake	1138	1170	0.52	0.84

(all expressed as mg/l)

The phosphate content of samples of water from the Hatfield Valley Aquifer indicated that that source has an average content of 0.06 mg/L with a range of 0.01 to 0.38 mg/L. Sawyer and McCarty (1978) determined that the minimum critical level of phosphate required to sustain a algal bloom is 0.015 mg/L.


ABOVE SEA LEVEL (m)
550
500
450
400
350
QU'APPELLE VALLEY
TILL
FLORAL FORMATION
KATEPWA
LAKE
SPRINGS
ECHO LAKE GRAVEL
QU'APPELLE ALLUVIUM
HATFIELD VALLEY
AQUIFER
RIDING MOUNTAIN FORMATION
GROUNDWATER FLOW
WATER TABLE
0
.5
1
km.

After E.A. Christiansen et al. 1981

Figure 4. Stratigraphic cross-section through Katepwa Lake showing inflow of groundwater.

To expect that a small water diversion of perhaps 3 to 4 m^3/sec entering the first lake of the chain could improve the water quality in the Fishing Lakes and relieve the algal blooms denies the interaction of the lakes and the physcial environment and denies an understanding of the mass balances of conservative materials in the diverted flow. With an investigation and understanding of the physical environment, expectations for water diversions may be more realistic.

SSEWSS - Blackstrap Reservoir

The Southeast Saskatoon Water Supply System (SSEWSS) was developed in the mid 1960's to supply water from Lake Diefenbaker for industrial, domestic, agricultural and recreational uses to communities south and east of Saskatoon.

The water is pumped from Lake Diefenbaker and conveyed by gravity canals to five storage reservoirs in series (Figure 5). The first two reservoirs, Broderick and Brightwater, and the canal systems that supply them and the next reservoir, Blackstrap, are passive (Davis and Sauer, 1983). The water undergoes little or no change until it reaches the Blackstrap Reservoir. Water quality deterioration within that reservoir has been documented since 1969.

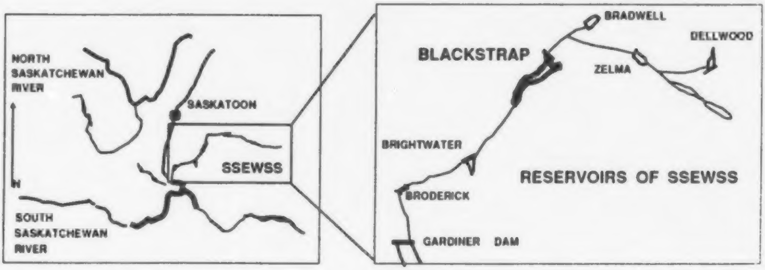


Figure 5: Schematic Diagram of the Location of the Reservoirs that make up the Saskatoon Southeast Water Supply System.

A comprehensive investigation of the physical environment of the Blackstrap Reservoir was initiated in 1986. The objectives of the investigation were:

- To define the geologic setting of the Blackstrap Reservoir,
- To characterize the chemistry of the groundwater in the vicinity of the Reservoir,
- To characterize the water quality in the Blackstrap Reservoir
- To determine if there is a connection between the groundwater regime and the reservoir.

The boundaries of the Blackstrap Region surrounding the Blackstrap

Reservoir were defined. The climate of the study region was determined from records of Canadian climate normals published by Environment Canada. The physiographic regions of the area and the assoicated soils were obtained from Acton et al.,(1960) and Ellis et al.(1970). To understand the physical environment of the study region, a review of existing publication concerning the geology, stratigraphy, lithology and hydrogeology was undertaken. The stratigraphy of the Blackstrap Reservoir at the causeway is shown in Figure 6. Aerial photographs and reports of Engineering or Geological activities were investigated. A matte mylar positive base map of the study region was prepared.

Information from many hundreds of existing testholes and water wells was collected. Cross-sections were prepared to define the geology of the study region. The contact between the Lea Park Formation and the overlying Judith River Formation was chosen as the base of water well exploration because DOE records show no wells completed in the Lea Park Formation.

From the information plotted on the base map, water wells were chosen for sampling and water level measurement. Wells completed in different stratigraphic formations were chosen to give a complete hydrochemical profile. All of the water samples were tested for major ions at the Environmental Engineering Laboratory, University of Saskatchewan.

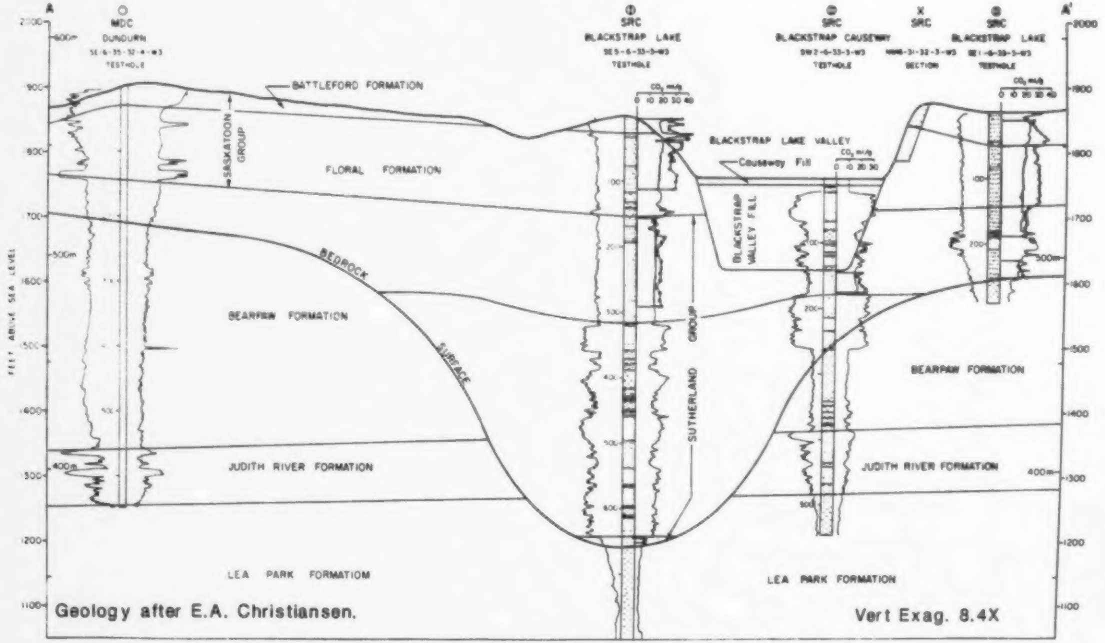
The groundwater of the Judith River Formation in the Blackstrap Region is characterized by high TDS, very high sodium concentrations that dominate the cation chemsitry and either very high chloride or sulfate concentrations that dominate the anion chemistry. The groundwater of the Bearpaw Formation in the Blackstrap Region is a sodium (calcium-magnesium)-sulfate type. Drift groundwater in the Blackstrap Region is either a calcium-bicarbonate type or a calcium-sulfate type.

Water levels or hydraulic heads of wells located in the Judith River Formation were plotted on an overlay to the base map. From this plot, contours of hydraulic head in the Judith River Formation were interpreted. The Judith River Formation was shown to be flowing artesian in the Reservoir area.

Analysis of water chemistry data for the Blackstrap Reservoir for the years 1969 to 1987 has shown a clear deterioration in the quality of the water from the south to the north end of the reservoir. Heuchert and Waters (1970) demonstrated a significant increase in TDS, chloride and Total Hardness from the south to the north end of the reservoir. Davis and Sauer (1983) stated that the calcium-bicarbonate type water that enters the inlet of the Blackstrap Reservoir changes immediately to a sodium-sulfate type water, and continues to deteriorate with distance from the inlet.

The results of these water quality determinations were reviewed and the following conclusions were drawn. There is a marked increase in the concentration of sodium and sulfate ions, and in TDS from the south to the north end of the Blackstap Reservoir. There is a slight increase in the concentration of calcium, magnesium and chloride ions, and Total Alkalinity. The water at the inlet of Blackstrap is a calcium-bicarbonate type water with low TDS. Calcium ions represent approximately 45% of the cation concentration. Magnesium ions represent about 30%, and sodium ions account for the remaining approximately 25% of the cation concentration. The bicarbonate ion makes up 65% of the anion concentration.

CROSS SECTION ACROSS BLACKSTRAP LAKE VALLEY


A
A'
FEET ABOVE SEA LEVEL
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
600m
500m
400m
MDC
DUNDURN
SE-6-35-32-4-W3
TESTHOLE
SRC
BLACKSTRAP LAKE
SE5-6-33-3-W3
TESTHOLE
SRC
BLACKSTRAP CAUSEWAY
SW2-6-33-3-W3
TESTHOLE
SRC
NW6-31-32-3-W3
SECTION
SRC
BLACKSTRAP LAKE
SE1-6-33-3-W3
TESTHOLE
CO2 ml/g
0 10 20 30 40
0 10 20 30
BATTLEFORD FORMATION
SASKATOON GROUP
FLORAL FORMATION
BEDROCK SURFACE
BEARPAW FORMATION
JUDITH RIVER FORMATION
LEA PARK FORMATIOM
SUTHERLAND GROUP
BLACKSTRAP LAKE VALLEY
Causeway Fill
BLACKSTRAP VALLEY FILL
LEA PARK FORMATION
100
200
300
400
500
600

Geology after E.A. Christiansen.

Vert Exag. 8.4X

Figure 6. Stratigraphic cross-section of the Blackstrap Reservoir.

Chloride is present in minor amounts, about 1%, and sulfate makes up the other 34% of the anion concentration. Between the south inlet and the north outlet of the Blackstrap Reservoir, the hierarchy of cations and anions changes. This redistribution of the percentages of ions is evident for all sampling periods.

At the north end of the reservoir the water is a sodium-sulfate type. The sodium ion concentration has increasesd from about 25%, to 35% to 40% of the total cation concentration. The magnesium ion concentration has increased from about 30%, to 35% to 40%. The calcium ion concentration has decreased to about 25%. The sulfate ion has increased to about 65% of the anion balance, the chloride concentration has increased to about 5%, and the bicarbonate concentration has decreased to about 30%.

The exact quantity in mg/L of TDS and the major ions for each sample location may vary from year to year, however, the trend of an increase in individual ion concentrations from south to north is consistent. This increase in individual ion concentration and in TDS with distance from the inlet for one sampling period is shown in Table 3.

Table 3. Major ions for the Brightwater Reservoir and the four sampling points in the Blackstrap Reservoir.

Location	Na	Ca	Mg	K	T.Alk	Cl	SO_4	TDS
July 1987								
Brightwater	20	35	17	2	135	2	61	237
Blackstrap Inlet	22	41	15	3	141	3	66	252
Blackstrap Southend	33	42	21	4	147	2	116	343
Blackstrap Causeway	48	48	29	6	160	12	169	443
Blackstap Northend	76	50	42	8	173	15	269	609

*all expressed as mg/L of the ion except T.Alk which is in mg/l of CaCO3.

In summary, past field observations indicate that the former valley of the Blackstrap Reservoir was a discharge area. The water in the Blackstrap Reservoir undergoes a change in chemistry from the south to the north end. It changes from a calcium-bicarbonate type water with TDS about 300 mg/L to a sodium-sulfate type water with TDS about 700 mg/L. This change in water chemistry and increase in TDS is a result of groundwater discharge primarily from the Judith River Formation and secondarily from the Bearpaw Formation. This conclusion is based on hydraulic head and hydrochemical information from wells in the Blackstrap Reservoir Region. It is not possible to determine whether groundwater discharge from the drift is a significant contributor to the water quality deterioration in the Blackstrap Reservoir. The results of this investigation have shown conclusively that the water quality deterioration that occurs in the Blackstrap Reservoir is due to an inflow of groundwater from the Judith River Formation. This has been demonstrated hydrochemically as well as physically.

SUMMARY

A methodology for reservoir site selection is required to evaluate the impact of the physical environment of the proposed reservoir site on the quality of the impounded water. Potential reservoir locations such as the Anerley Channel and Tramping Lake warrant further study if they are to be considered as transport or storage reservoirs in a major diversion. Water quality in both the Qu'Appelle Diversion and SSEWSS, specifically the Blackstrap Reservoir, has been shown to be affected by their physical environments.

CONCLUSIONS

1. There can be a significant impact on water quality when water is transferred from one basin to another.

2. Water quality may undergo deterioration as a result of groundwater discharge into a storage or transportation reservoir.

3. In order to avoid past mistakes, the objectives for transporting water should have clearly stated, reasonable objectives based on scientific reasoning.

4. A cost-effective methodology for locating future reservoirs and routing interbasin transfers to minimize water quality deterioration is required.

ACKNOWLEDGEMENTS

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EFFETS DE LA COUPURE DES RIVIÈRES EASTMAIN-OPINACA ET CANIAPISCAU EN AVAL DES OUVRAGES DE DÉRIVATION

D. MESSIER[1] et D. ROY[1]

RÉSUMÉ

La création du Complexe hydroélectrique de la Grande Rivière a nécessité le détournement des bassins supérieurs des rivières Eastmain et Opinaca (810 m^3/s), au sud de La Grande Rivière, et de la rivière Caniapiscau (776 m^3/s), à l'est. Ces trois rivières originent du Bouclier canadien mais leurs cours résiduels découpent soit les sédiments fins de la mer de Tyrrell (Eastmain et Opinaca), soit surtout des dépôts fluvioglaciaires (Caniapiscau et Koksoak). En aval des ouvrages de dérivation, les apports des rivières Eastmain et Opinaca ne provenant que d'un bassin résiduel aux eaux plus minéralisées, en plus de l'augmentation du temps de contact causé par le faible débit, ont provoqué une hausse de la turbidité, du pH et du niveau de la plupart des éléments nutritifs et des ions majeurs. Sur la Caniapiscau toutefois, la qualité de l'eau du cours résiduel est demeurée pratiquement inchangée. Les principales répercussions écologiques perçues proviennent de la réduction du volume d'eau, d'une plus grande stabilité et des modifications de la qualité de l'eau: augmentation de la densité zooplanctonique et des rendements de pêche, adaptation de certaines espèces aux modifications de la qualité de l'eau. La réponse des milieux estuariens s'est traduite par un déplacement vers l'amont des zones de mélange et de sédimentation et les organismes vivants ont simplement suivi ces déplacements.

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INTRODUCTION

La création du Complexe hydroélectrique de La Grande Rivière a nécessité le détournement des bassins supérieurs des rivières Eastmain et Opinaca, au sud de La Grande Rivière, et de la rivière Caniapiscau, à l'est. La création du réservoir Opinaca s'est faite par la coupure séquentielle de la Petite rivière Opinaca en juillet 1979 (3%), de la rivière Opinaca en avril 1980 (15%) et de la rivière Eastmain en juillet 1980 (72%) pour un total de 810 m^3/s, représentant 90% du débit initial mesuré à l'estuaire. Depuis octobre 1981, date à laquelle le barrage de Duplanter a été complété, les eaux situées en amont de celui-ci s'accumulent dans le réservoir Caniapiscau et ne feront plus partie, de façon régulière, du bassin de drainage de la baie d'Ungava. La rivière Caniapiscau a perdu 40% (776 m^3/s) de son débit à la confluence avec la rivière Koksoak et celle-ci, 28% à son embouchure (Fig. 1).

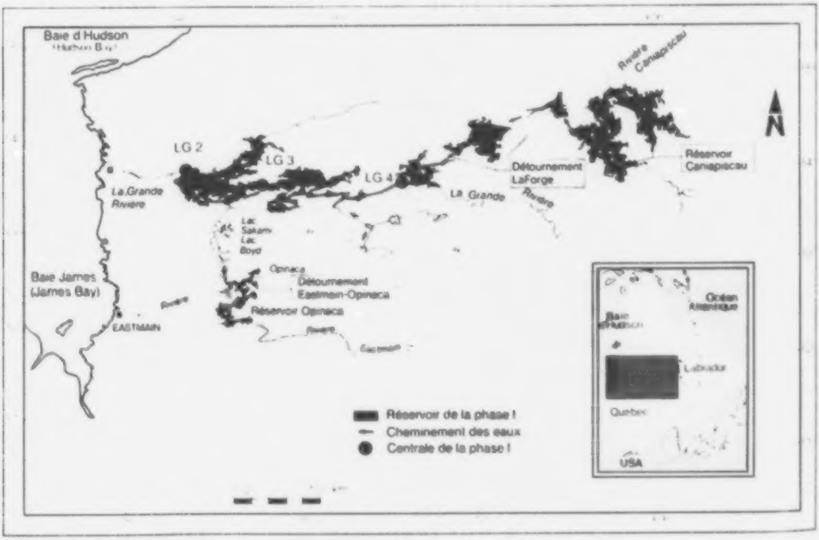
Baie d Hudson
(Hudson Bay)
Rivière Caniapiscau
LG 2
LG 3
LG 4
La Grande Rivière
Détournement LaForge
La Grande Rivière
Réservoir Caniapiscau
N
Lac Sakami
Lac Boyd
Opinaca
Détournement Eastmain-Opinaca
Réservoir Opinaca
Baie James
(James Bay)
EASTMAIN
Rivière
Rivière Eastmain
Baie d'Hudson
Océan Atlantique
Labrador
Québec
USA
Réservoir de la phase I
Cheminement des eaux
Centrale de la phase I

Fig. 1 Le complexe hydroélectrique de La Grande Rivière.

Consciente qu'un projet de cette envergure entraînerait inévitablement des modifications importantes des écosystèmes aquatiques, la Société d'énergie de la Baie James (SEBJ) réalisait, de 1977 à 1984, un vaste programme de surveillance écologique. Outre l'évolution des réservoirs et des voies de détournement, la direction Ingénierie et Environnement a suivi les changements survenus dans les rivières à débit réduit et leurs estuaires. Ces résultats sont les premiers, à notre connaissance, à être décrits pour de grandes rivières en milieu nordique. Les résultats de ces suivis apparaissent dans deux rapports synthèses (SEBJ-SOTRAC 1985; Lalumière et al. 1985). Nous traiterons des principales modifications qui se sont produites dans le cours aval des rivières détournées.

MATÉRIEL ET MÉTHODES

Description du territoire

Le Nord du Québec est entièrement compris dans le Bouclier canadien. Le socle rocheux comprend majoritairement des roches ignées, métamorphiques ou volcaniques très anciennes à l'exception de roches sédimentaires appartenant à la fosse du Labrador, à l'est, et aux collines de Povungnituk au nord. La majorité des matériaux de surface sont des dépôts minces de moraine laissés sur place il y a 7000 à 9000 ans, lors de la fonte des glaces. Entre les altitudes de 200 à 300 m subsistent encore les vestiges de quelques lacs glaciaires dont le plus important, Ojibway-Barlow, se situe au sud-ouest, près de la frontière de l'Ontario. Les dépôts d'argile lacustre sont particulièrement épais dans cette région. Tout autour des mers, à des altitudes inférieures à 200 m et parfois 300 m, des dépôts d'argile marine, de sable et de matières organiques (tourbières) se sont accumulés sur la moraine; ces dépôts peuvent avoir plusieurs dizaines de mètres d'épaisseur près de la mer.

Les rivières Eastmain et Opinaca découpent, en aval des ouvrages de dérivation, des sédiments silto-argileux mis en place par la mer de Tyrrell; ces dépôts sont, à certains endroits, recouverts de minces couches morainiques. Pour leur part, les rivières Caniapiscau et Koksoak se sont encaissées principalement dans des dépôts fluvio-glaciaires; les sédiments argileux laissés en place par l'invasion de la mer d'Iberville ne se retrouvent pratiquement que sur les rives du lac Cambrien et sporadiquement en aval de celui-ci (Fig. 2).

Échantillonnage et méthodes d'analyse

Dans la région des rivières Eastmain et Opinaca, deux stations ont été opérées régulièrement de 1978 à 1984 et quatre autres durant quelques années seulement; nous ne présenterons la physico-chimie que pour les deux premières qui fournissent les meilleures séries temporelles (Fig. 3). Les relevés physico-chimiques étaient faits toutes les deux semaines durant la période libre de glace. A chaque station, la température, l'oxygène dissous et la conductivité étaient mesurés in situ de la surface au fond; un échantillon d'eau représentant une colonne d'eau, de la surface au fond, était également prélevé. En plus des pigments chlorophylliens, les paramètres analysés en laboratoire étaient: le pH, la conductivité, la couleur réelle, la turbidité, les matières en suspension, les ions majeurs (chlo-

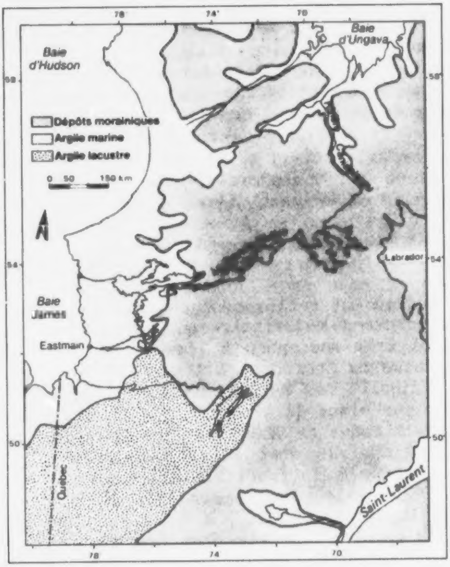
78
74'
70
Baie d'Ungava
Baie d'Hudson
58
58'
Dépôts morainiques
Argile marine
Argile lacustre
0 50 150 km
N
54
Labrador
54'
Baie James
Eastmain
50
50'
Québec
Saint-Laurent
78
74
70

Fig. 2 Répartition des matériaux de surface dans le Nord du Québec.

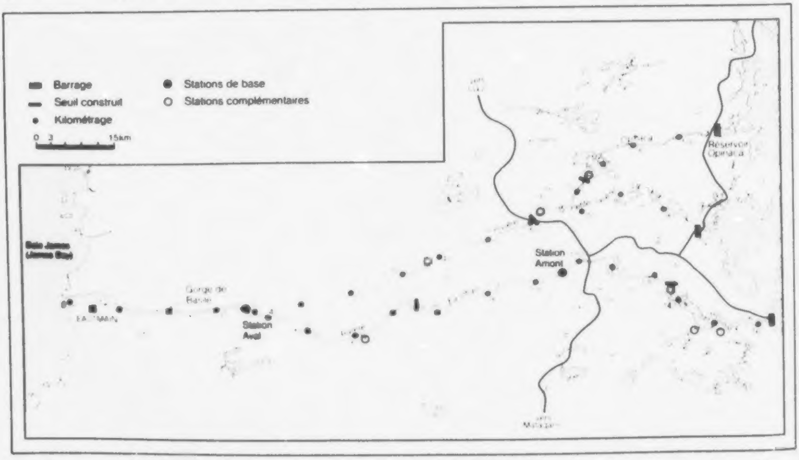
Barrage
Seuil construit
Kilométrage
0 3 15km
Stations de base
Stations complémentaires
Baie James (James Bay)
EASTMAIN
Gorge de Basile
Station Aval
Station Amont
Opinaca
Réservoir Opinaca

Fig. 3 Stations d'échantillonnage de la qualité de l'eau sur les rivières Eastmain et Opinaca.

rures, bicarbonates, sulfates, sodium, potassium, calcium, magnésium), les ions mineurs (fer et manganèse), les éléments nutritifs (phosphore total, azote Kjeldahl, carbone inorganique total, carbone organique total, silice) et les tanins et lignine. Les méthodes d'analyse en laboratoire sont celles décrites par l'American Public Health Association (1971).

Aux deux mêmes stations et selon la même fréquence, les organismes zooplanctoniques étaient recueillis à l'aide d'un filet Clarke-Bumpus (mailles de 75 cm d'ouverture) tiré obliquement du fond à la surface de façon à filtrer un volume d'eau variant de 500 à 1000 L.

A ces mêmes stations et à quatre autres sites, des pêches étaient réalisées à l'aide de filets maillants expérimentaux de 45 m de long sur 2,4 m de large (mailles étirées de 2,5 à 10,2 cm). Les filets étaient tendus chaque mois, de juin à octobre, durant des périodes variant habituellement de 24 à 48 heures. Les poissons étaient mesurés et pesés, le sexe et la maturité sexuelle étaient déterminés et le coefficient de condition (K) a été calculé pour les espèces de poissons les plus abondantes.

Les études d'océanographie dans l'estuaire de la rivière Eastmain (0-27 km) se sont échelonnées de 1979 à 1984. Exécuté d'abord par une équipe interuniversitaire (GIROQ), puis par la SEBJ, le programme a sensiblement changé au cours des années. Certains détails de ce programme apparaissent dans Ingram (1982), Grenon (1982), Ochman et Dodson (1982), Lambert et Dodson (1982), d'Anglejan (1982), Ingram et al. (1985), Messier (1985a) et Messier et al. (1986).

Le suivi environnemental des rivières Caniapiscau et Koksoak n'a débuté qu'en 1980. Les mêmes méthodes ont été conservées à une station régulière sur le cours résiduel de la rivière Caniapiscau (Fig. 4); des stations complémentaires dont le nombre et la fréquence ont varié selon les besoins ont été ajoutées entre 1980 et 1984.

Dans l'estuaire de la rivière Koksoak, en raison de son éloignement et de l'ampleur de ses marées, seules la propagation de la marée (amplitude et phase) et la variation de la salinité ont été suivies par la SEBJ. La recherche pour établir les niveaux de récolte des poissons de la rivière Koksoak a été confiée par la SEBJ à la Société Makivik. Les détails de ce programme apparaissent dans Gillis et Kemp (1983) et Messier (1985b).

RÉSULTATS ET DISCUSSION

Qualité de l'eau

Avant le détournement, les eaux de la rivière Eastmain étaient légèrement acides (pH de 6,3), peu tamponnées (3 mg/L de HCO_3), pauvres en substances dissoutes (faible conductivité) et moyennement transparentes (3 à 4 UTN). Le brassage causé par les nombreux rapides en amont se traduisait par une oxygénation maximale. Les concentrations en phosphore total

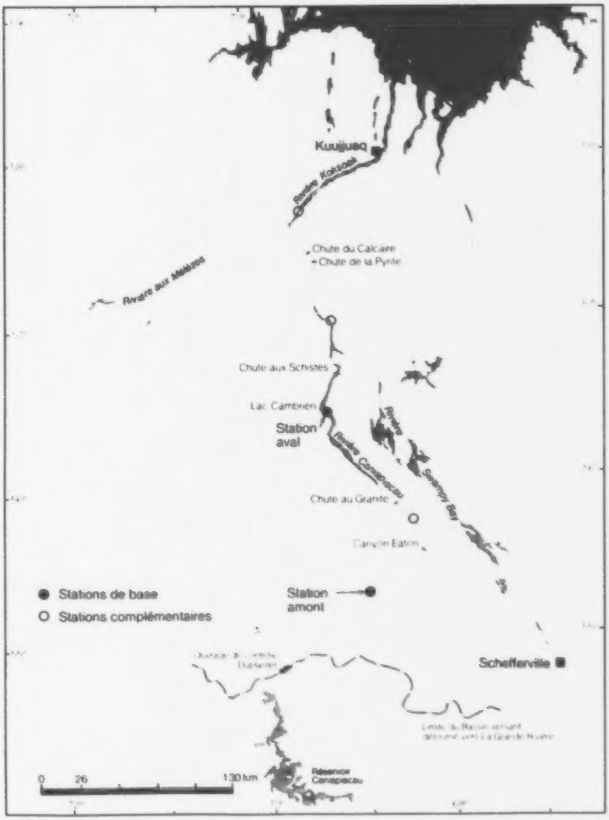
Kuujjuaq
Rivière Koksoak
Chute du Calcaire
Chute de la Pyrite
Rivière aux Mélèzes
Chute aux Schistes
Lac Cambrien
Station aval
Rivière Caniapiscau
Rivière Swampy Bay
Chute au Granite
Canyon Eaton
● Stations de base
○ Stations complémentaires
Station amont
Schefferville
Réservoir Caniapiscau
0
26
130 km

Fig. 4 Stations d'échantillonnage de la qualité de l'eau sur les rivières Caniapiscau et Koksoak.

(15 ug/L) et en azote Kjeldahl total (0,15 mg/L), quoique faibles, permettaient une certaine production phytoplanctonique (1,0 à 1,5 ug/L de chlorophylle). Une couleur légèrement brune (40 unités Hazen) et un taux de carbone organique total relativement élevé (8,0 mg/L) reflétaient la présence des nombreuses tourbières drainées par cette rivière. L'azote ammoniacal, les nitrates et les nitrites ont été mesurés, mais ils étaient toujours sous le seuil de détection (0,2 mg/L) (tableau 1).

Tableau 1: Moyennes estivales de quelques paramètres physico-chimiques de la rivière Eastmain avant et après la coupure (juillet 1980) en aval de l'ouvrage de dérivation.

	1978		1981		1984	
	Amont	Aval	Amont	Aval	Amont	Aval
Couleur (unité Hazen)	37	44	94	102	84	95
Turbidité (UTN)	3,8	4,0	21,8	33,0	11,2	20,9
Oxygène dissous (%)	105	101	95	92	91	90
pH	6,3	6,3	6,6	6,9	6,4	6,7
Conductivité (uS/cm)	13	14	29	36	21	26
Chlorures (mg/L Cl)	0,3	0,3	2,5	3,2	1,6	2,1
Bicarbonates (mg/L HCO_3^-)	3,1	3,2	5,2	9,0	3,3	5,9
Potassium (mg/L K)	0,3	0,4	1,0	1,6	0,8	1,1
Phosphore total (ug/L P)	18	17	30	49	21	37
Azote Kjeldahl total (mg/L N)	0,18	0,17	0,25	0,28	0,24	0,29
Carbone inorg. total (mg/L C)	0,8	0,9	1,3	2,0	1,0	1,4
Carbone org. total (mg/L C)	7,5	8,0	12,7	12,6	12,3	13,4
Chlorophylle a (ug/L)	1,52	1,51	2,10	2,33	1,73	1,57

Un gradient positif amont-aval caractérisait la rivière Eastmain pour ce qui est du pH et de la concentration de la plupart des substances dissoutes dans les rivières Eastmain et Opinaca. Ce gradient reflète la formation géologique du bassin: à l'est, dépôts glaciaires et roches ignées (résistantes à l'action de l'eau) et, à l'ouest, sédiments marins et dépôts organiques (tableau 1).

Le premier été suivant la coupure de la rivière (1981), la concentration moyenne estivale de la plupart des paramètres de la qualité de l'eau a augmenté de façon nette. Cette augmentation s'est surtout fait sentir sur la turbidité (plus de 20 UTN), la conductivité (plus de 30 uS/cm), les éléments nutritifs et les matières organiques (couleur, azote Kjeldahl et carbone organique total). En 1984, cette tendance est encore manifeste quoique les paramètres liés à l'érosion des rives aient régressé (tableau 1). La rivière Opinaca a connu des modifications similaires.

Le principal effet de la coupure du débit des rivières Eastmain et Opinaca fut de restreindre le bassin versant au secteur aval des rivières où se rencontrent majoritairement des argiles marines, des silts et des tourbières ombrotrophes; c'est aussi dans ce secteur que les rives des rivières sont les plus érodables. Il est donc logique que les valeurs des paramètres qui sont sensibles à la mise en suspension des argiles, des silts et des matières organiques augmentent. De plus la réduction du niveau des eaux a causé une augmentation à court terme des argiles en suspension par l'érosion des rives et le surcreusement de la partie aval des tributaires. Ces phénomènes se sont estompés au cours des ans suite à la colonisation végétale des rives et au rehaussement du plan d'eau par quatre seuils érigés sur ces rivières. Cette réduction du débit a eu pour effet de réduire la turbulence et d'augmenter le temps de séjour des eaux et donc le temps de contact des eaux avec les sédiments et les argiles marines. A court terme toutefois, il n'y a qu'une partie de l'augmentation des paramètres reliés aux matières en suspension qui peut être attribuée aux propriétés de l'eau du bassin versant résiduel, la différence provenant de l'érosion qu'ont subie les rives suite à leur exondation. A long terme, on prévoit que lorsque le niveau d'érosion se sera stabilisé, la qualité de l'eau dépendra majoritairement des propriétés du bassin versant résiduel.

Ceci est vérifié par les observations faites sur la rivière Caniapiscau. Grâce à sa géologie (roche en place et matériaux meubles grossiers), cette rivière coupée a été peu sujette à l'érosion des rives et la qualité de l'eau, en amont de la confluence avec la rivière Swampy Bay, a été en tout point comparable à celle des eaux du bassin versant résiduel. Ces dernières étant en grande partie qualitativement comparables aux eaux de la Caniapiscau, la qualité de l'eau est demeurée essentiellement la même qu'antérieurement (tableau 2).

Productions primaire et secondaire

Le phytoplancton a profité de la lacustration des rivières pour augmenter sa production annuelle comme l'indiquent les concentrations de chlorophylle *a* observées dans la rivière Eastmain (tableau 1). Cet accroissement fût causé par la réduction des vitesses de courant de l'enrichissement des eaux en matières nutritives et ce, malgré une diminution de la transmission lumineuse. En aval du réservoir Caniapiscau, la réduction des apports provenant des lacs en amont, le peu d'apports supplémentaires de matières nutritives et la compétition avec le périphyton établi dans le lit de la rivière, n'ont pas réussi à maintenir un niveau équivalent de biomasse phytoplanctonique (tableau 2).

Lors de la coupure de débit sur les rivières Eastmain et Opinaca, les temps de résidence des eaux dans les sections les plus lentes sont passés de moins d'un jour jusqu'à 23 jours pour l'une d'elles et, après érection d'un seuil jusqu'à 43 jours. Les organismes zooplanctoniques ont réagi à ces fluctuations en passant d'un niveau de densité et de biomasse plutôt instable, typique des rivières, à celui des lacs; les populations de rotifères, de cladocères et de copépodes cyclopoïdes se sont rapidement développées atteignant des valeurs de 10, 30 ou plus élevées qu'avant le détournement (tableau 3). Une analyse en composantes principales a dévoilé que l'accroissement de la masse zooplanctonique n'était pas surtout dû à l'enrichissement des eaux en matières dissoutes ou en suspension mais plutôt à la diminution du taux de renouvellement des eaux. Le traitement des données par la méthode des régressions multiples mène à la même conclusion (Roy 1985).

Tableau 2: Moyennes estivales de quelques paramètres physico-chimiques de la rivière Caniapiscau avant et après la coupure (octobre 1981) en aval de l'ouvrage de dérivation.

	1981		1983	
	Amont	Aval	Amont	Aval
Couleur (unité Hazen)	20	15	22	22
Turbidité (UTN)	1,1	1,0	1,6	1,4
Oxygène dissous (%)	97	98	95	94
pH	6,3	6,6	6,5	6,6
Conductivité (uS/cm)	10	11,5	12	16,4
Chlorures (mg/L Cl)	0,2	0,3	0,3	0,3
Bicarbonates (mg/L HCO_3^-)	2,4	3,4	3,04	5,64
Potassium (mg/L K)	0,3	0,3	0,3	0,4
Phosphore total (ug/L P)	6	5	6	5
Azote Kjeldahl total (mg/L N)	0,11	0,11	0,16	0,14
Carbone inorg. total (mg/L C)	0,9	1,0	1,2	1,9
Carbone org. total (mg/L C)	4,9	4,7	5,6	4,9
Chlorophylle _a_ (ug/L)	1,16	1,15	0,81	0,84

Sur la rivière Caniapiscau, à la station située le plus en amont (tableau 3), le temps de séjour est de l'ordre de 1 à 2 jours et, malgré la réduction du débit, est demeuré sensiblement le même. Les densités et biomasses des zooplanctonctes sont donc semblables avant ou après la modification du débit. Cependant dans les sections lentes, les mêmes mécanismes que ceux décrits sur la rivière Eastmain ont sans doute joué.

Poissons

Des rendements journaliers moyens nettement plus importants qu'avant la coupure du débit de la rivière Eastmain ont été obtenus en 1980 et en 1981, à la station située à mi-chemin entre le réservoir Opinaca et la baie James. Ils étaient 5 fois plus élevés que précédemment et l'augmentation soudaine des rendements de pêche tient principalement au phénomène de concentration des poissons qui résulte de la diminution du volume d'eau.

En 1982, après la construction d'un seuil, les rendements de pêche à ce site sont demeurés semblables, soit 41,6 poissons et 41,1 kg par filet-jour et les abondances relatives des espèces ont peu varié. Ce n'est qu'en 1983 et 1984 que les rendements se sont appauvris: environ 25 poissons et 25 kg par filet-jour. Au cours de ces deux dernières années, les rendements étaient encore 3 fois plus élevés qu'aux conditions antérieures à la coupure du débit. Ce sont l'esturgeon de lac et le grand corégone qui sont surtout responsables de la baisse des effectifs des deux dernières années (Fig. 5).

Tableau 3: Densités (N/m^3) et masses (ug/m^3) moyennes annuelles des récoltes de zooplancton sur les rivières Eastmain et Caniapiscau en aval de leurs ouvrages de dérivation.

	Eastmain						Caniapiscau	
	1978		1981		1984		1981	1983
	Amont	Aval	Amont	Aval	Amont	Aval	Amont	Amont
Densité:								
Copépodes	116	288	9761	6305	8655	1950	134	150
calanoïdes	87	209	152	341	1785	133	33	5
cyclopoïdes	29	44	1816	1680	960	487	39	30
nauplies	-	35	7793	4284	5910	1330	62	115
Rotifères	321	641	15856	16117	12079	8193	2649	1560
Cladocères	32	34	2068	1097	1698	539	49	24
Total:	469	962	27685	23520	22431	10682	2834	1733
Masses:								
Copépodes	471	654	4878	5803	12005	1352	210	72
calanoïdes	416	582	690	2074	9092	324	110	11
cyclopoïdes	55	67	3097	3129	2086	842	91	45
nauplies	-	5	1091	600	827	186	9	16
Rotifères	9	19	883	677	613	669	52	62
Cladocères	119	50	8669	2608	8745	1296	203	59
Total:	599	723	14430	9087	21364	3317	469	193

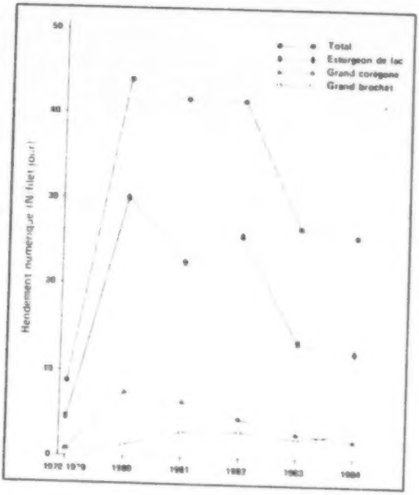

Fig. 5 Rendements numériques des pêches effectuées dans la rivière Eastmain avant et après la réduction des débits (juillet 1980).

Selon les longueurs obtenues, le recrutement des jeunes de l'année a semblé normal chez le grand corégone, le grand brochet, le meunier rouge et le meunier noir. Il a paru meilleur pour le doré et plus faible pour l'esturgeon de lac.

Dès 1981, la plupart des espèces, sauf le grand brochet, ont connu une baisse de leur coefficient de condition moyenne; par la suite, de 1981 à 1984, les valeurs moyennes sont demeurées comparables à celles de 1981. Cette situation illustre vraisemblablement certaines difficultés d'adaptation aux nouvelles conditions de survie dans ce milieu et à une plus faible disponibilité de nourriture par individu.

Du barrage de Duplanter (km 592) à la chute du Calcaire (km 164), les rendements de pêche sont demeurés semblables à la suite de la coupure du débit et ont même légèrement augmenté (tableau 4).

Malgré qu'une pêche importante ait eu lieu sur les premiers 100 km du nouveau cours d'eau (Duplanter-Eaton) en 1982, les rendements moyens ont augmenté sur presque tous les tronçons. Il est possible que la réduction de l'activité fluvio-glacielle après la coupure puisse augmenter les chances de survie des recrues. D'ailleurs un accroissement de l'abondance relative des jeunes a été constaté au cours des pêches de 1984. On remarque également une augmentation des coefficients de condition chez toutes les principales espèces (meunier rouge, grand corégone et touladi).

Tableau 4: Rendements numériques moyens des diverses espèces de poissons pêchées dans cinq tronçons de la rivière Caniapiscau, en 1980 et 1984.

Espèces	Tronçons									
	Duplanter Eaton		Eaton Granite		Granite Schistes		Schistes Pyrite		Pyrite Calcaire	
	1980	1984	1980	1984	1980	1984	1980	1984	1980	1984
Touladi	0,1	0,7	1,1	1,0	1,2	1,9	2,7	4,3	14,0	20,8
Ouananiche	0,7	0,2	0	0	0	0,5	0,8	0,4	0	0
Omble de fontaine	2,1	4,4	0,6	1,5	0	0	0,4	0	6,0	9,1
Corégone	0,3	2,9	0	0	4,7	5,8	3,7	2,0	6,0	9,1
Ménomini	0,3	1,8	2,2	0,5	0,2	1,0	0,6	0	16,0	32,4
Meunier rouge	17,9	25,7	3,8	2,5	3,5	7,9	4,7	6,7	8,0	24,7
Meunier noir	1,0	0,8	2,4	0	2,1	3,4	0	0,4	3,0	2,6
Lotte	0	0,5	0	0	0	0,5	0	0,4	0	0
Brochet	0	0,15	0	0	2,7	3,0	1,4	0	0	0
Autres	0,3	0,8	1,8	0	1,3	0,9	2,7	0,8	1,0	0
Total	22,6	37,9	11,8	5,5	15,6	24,9	17,1	14,9	54,0	98,6

L'estuaire de la rivière Eastmain

Les modifications physiques et biologiques survenues dans l'estuaire de la rivière Eastmain sont exposées dans Messier et al. (1986). Les principales conclusions sont reprises ici, en relation avec les changements en amont.

La réduction du débit d'eau douce à l'estuaire a provoqué l'augmentation de l'influence maritime. La zone de mélange des eaux douces et salées et la zone de déposition des particules fines ont avancé d'une dizaine de kilomètres, en réponse à la baisse du niveau de l'eau et aux modifications de la dynamique des courants.

L'augmentation de la stabilité (Ingram et al. 1985) et les modifications de la qualité de l'eau en amont ont encouragé une croissance phytoplanctonique plus grande. L'intrusion des eaux salées et le passage d'un estuaire en phase d'érosion à une zone de déposition ont favorisé l'implantation d'espèces estuariennes et dulçaquicoles très eurytopiques, telles Macoma balthica et les larves de Chironomidae.

Les rendements de pêche en 1984 étaient similaires à ceux rencontrés en conditions naturelles, dans des zones écologiquement semblables. De plus, rien n'indique que l'utilisation des sites connus pour la reproduction des corégonidés (grand corégone et cisco) n'ait été différente. D'ailleurs les tailles des poissons capturés en 1984 indiquent que le recrutement des individus nés depuis la coupure s'effectue normalement, sinon avec un succès légèrement accru (Fig. 6). L'augmentation de la stabilité, de la densité des organismes benthiques et possiblement de celle des organismes zooplanctoniques pourraient favoriser les poissons; d'ailleurs la croissance du grand corégone semble avoir augmenté entre 1974 et 1984.

Dans leur étude du doré de l'estuaire de la rivière Eastmain, Belzile et Dodson (1984) émettent l'hypothèse que les immatures se déplacent de la partie supérieure de la rivière vers la limite du front salin dans le but de s'y alimenter. Les données de 1984 ne supportent pas cette hypothèse car les dorés de toutes tailles sont répartis uniformément dans l'estuaire fluvial et leur régime alimentaire ne semble pas sélectif. En effet 10 des 12 dorés récoltés dans la zone d'oscillation du front salin avaient une taille supérieure à 360 mm, étant probablement âgés de plus de 5 ans; par ailleurs les 10 individus de moins de 275 mm ont été pêchés dans les quatre secteurs de l'estuaire fluvial.

Avant le détournement, la répartition des poissons, et particulièrement des jeunes individus, était déterminée par le régime des courants. Sur l'ensemble de l'estuaire la vitesse moyenne était de l'ordre de 40 cm/s et des inversions de courant n'étaient rencontrées qu'à l'embouchure de la rivière. Les poissons de petites tailles étaient donc surtout concentrés près de l'embouchure. Depuis, la vitesse moyenne n'est plus que de 4 cm/s et des inversions de courant se produisent sur tout l'estuaire. Les deux facteurs favorisent une répartition uniforme des poissons de toutes tailles sur l'ensemble de l'estuaire.

Bernatchez et Dodson (1985) ont émis l'hypothèse que la vitesse rencontrée dans les rapides de la gorge de Basile était trop grande (0,7 à 1,5 m/s) pour permettre aux corégonidés de traverser ces rapides sans fatigue. Or en conditions naturelles les vitesses étaient certainement plus grandes encore. Force est d'admettre que l'accès aux sites présumés de reproduction est facilité par la coupure des débits ou que ces sites sont plutôt situés aux pieds des rapides. En haut des rapides, les rendements de pêche pour les deux espèces (grand corégone et cisco) ont été inférieurs à 15 poissons/filet-jour, ce qui n'est pas représentatif de concentrations de frai. En fait les adultes sont plutôt capturés en aval des rapides et à l'embouchure d'une petite rivière à proximité de ce site. Quel que soit le site exact de reproduction des corégonidés semi-anadromes, le frai se déroule normalement dans l'estuaire de la rivière Eastmain et des deux tributaires qui s'y jettent, depuis la coupure des rivières Eastmain et Opinaca.

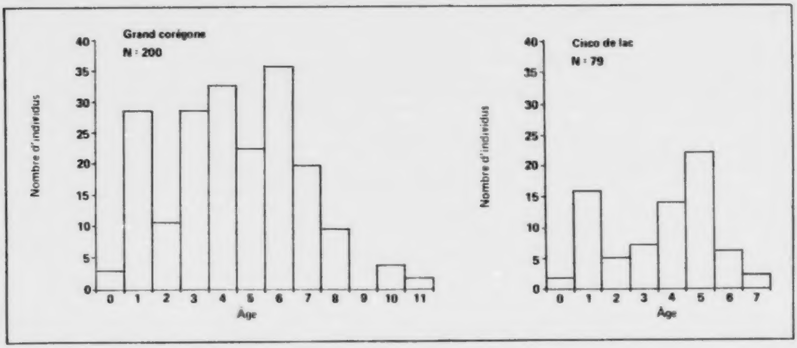

Fig. 6 Distribution de fréquences d'âges des grands corégones et des ciscos de lac pêchés dans l'estuaire de la rivière Eastmain en 1984.

L'estuaire de la rivière Koksoak

Dans l'ensemble, l'estuaire de la rivière Koksoak n'offre pas les conditions d'un écosystème riche au point de vue de la production primaire et secondaire endogènes, malgré l'intrusion des eaux de surface de la baie d'Ungava dans les premiers 50 km. La relative pauvreté des eaux de la rivière en éléments nutritifs, les forts courants, les variations journalières de la salinité et de la température causées par les marées (hauteur de 4,8 à 13,1 m à l'embouchure) constituent des facteurs peu propices à une telle production. La zone de mélange des eaux douces avec les eaux de surface de la baie d'Ungava semble cependant être un bon endroit en été pour la nutrition des poissons en raison des apports des deux types de masses d'eau.

Les résultats des captures de 1977 à 1986 apparaissent au tableau 5. Les résultats proviennent en partie des pêcheries commerciales et en partie de la pêche de subsistance, de sorte que l'effort de pêche est variable.

Le saumon atlantique et l'omble de fontaine sont les espèces les plus recherchées dans la rivière Koksoak; l'omble chevalier n'est pas un résident de la rivière tandis que les autres espèces, corégone, chaboisseau, meunier et touladi, le sont. Globalement le nombre de poissons capturés dans la rivière est le même avant (1977-1981) et après (1982-1986) le détournement de la rivière Caniapiscau. On remarque cependant une légère diminution du nombre de saumons de 1983 à 1985. Il est difficile d'attribuer cette baisse à la coupure car les frayères et les alevinières du saumon sont situées dans des tributaires de la rivière au Mélèzes, affluent de la Koksoak. Les faibles effectifs coïncident au départ tardif des glaces dans la baie d'Ungava, à l'arrivée tardive de saumons marins dans l'estuaire de la Koksoak et à une période de pêche tardive et écourtée. Dans un estuaire maritime agrandi par la réduction du débit d'eau douce, il serait étonnant que les formes anadromes ou semi-anadromes de poissons puissent subir des effets négatifs. Pour les espèces dulçaquicoles, l'estuaire fluvial et la section fluviale sont suffisamment importantes (80 km en été, 70 km en hiver) pour assurer la survie des espèces, pour tous leurs stades de développement.

Tableau 5. Captures en nombre des poissons de la rivière Koksoak avant (1977-1981) et après (1982-1986) la réduction du débit.

Année	Saumon	Omble de fontaine	Omble chevalier	Autres	Total
1977	4095	1750	557	1639	8041
1978	4508	2952	592	1738	9790
1979	3995	1066	263	658	5982
1980	9175	3021	789	2520	15505
1981	5500	1435	831	2153	9919
1978-1981	5454	2045	606	1742	9847
1982	5120	1128	246	1194	7688
1983	3854	2969	472	2935	10230
1984	3906	4548	436	4124	13014
1985	2399	2164	416	3292	8271
1986	5290	2858	289	2624	11061
1982-1986	4114	2733	372	2834	10053

CONCLUSION

L'aménagement du Complexe La Grande a nécessité le détournement des bassins supérieurs de deux rivières importantes dans le Moyen Nord québécois. Le principal effet de ces coupures a été de restreindre le bassin versant au secteur aval où les eaux sont généralement plus minéralisées; ce phénomène s'est fait sentir davantage sur les rivières Eastmain et Opinaca que sur la rivière Caniapiscau en raison des différences géologiques. Bien que l'abaissement du plan d'eau ait été sévère dans certains secteurs de rivière, la réponse des vivants s'est manifestée par une augmentation à la fois des producteurs et des poissons.

Les grandes rivières de cette région ne sont généralement pas de bons habitats pour les poissons. Ce n'est qu'à proximité des rares grands lacs et des estuaires que les effectifs sont importants: ailleurs, les rendements dans les rivières sont souvent trois ou quatre fois plus faibles que dans les lacs adjacents. Les conditions sévères causées par le climat, les fluctuations rapides des niveaux, les vitesses élevées de courant, la faible productivité et accumulations de glace et de frasil limitent le maintien à l'année longue de communautés de poissons riches et diversifiées. Les espèces rencontrées doivent jouir d'une grande plasticité de comportement, de faibles exigences alimentaires et d'un fort potentiel de rétablissement après les changements brusques. Elles tendent à occuper tous les milieux, même les eaux saumâtres, en autant que le leur permet leur organisme. Les estuaires fluviaux, les tronçons aval des rivières et les lacs servent souvent de refuge pour éviter les contraintes liées à l'hiver tant en milieux marins que lotiques (Roy 1987). Les coupures de rivière, loin de constituer un élément négatif pour les communautés piscicoles, auraient pour effet de diminuer certaines contraintes dans ces environnements. Cependant pour les espèces semi-anadromes, la réduction de la zone d'influence de ces rivières dans le milieu marin pourrait peut-être à long terme, entraîner une diminution globale des effectifs; ceci constitue un sujet à approfondir.

Dans l'estuaire de la rivière Eastmain, l'enrichissement et l'augmentation de la stabilité des eaux, suite à la coupure, amènent une augmentation de la biomasse phytoplanctonique et possiblement zooplanctonique. Lorsque la salinité est suffisamment élevée, des espèces marines se développent (Ingram et al. 1985) mais elles coexistent certainement avec des formes dulcicoles qui montrent généralement une grande tolérance aux variations de la salinité (Roff et Legendre 1986). Ces remarques s'appliquent également aux formes benthiques. Ces conclusions diffèrent considérablement des prévisions qui étaient fondées sur des hypothèses développées en milieu tempéré, la plus importante étant qu'un estuaire est alimenté en éléments nutritifs par ses apports d'eau douce. Or la rivière Eastmain est pauvre en éléments nutritifs et elle forme, dans la baie James, un important delta. Si cette rivière avait alimenté son estuaire et qu'il y ait existé des mécanismes de mélange des eaux profondes de la baie James (Messier et al. 1986), les conséquences des modifications hydrologiques auraient été fort différentes. A l'embouchure du Nil, les captures de poissons ont considérablement diminué suite à l'appauvrissement en éléments nutritifs des eaux lagunaires et marines consécutif à la réduction de 90% du débit moyen du Nil (Bebars et Lasserre 1983). Dans l'estuaire de la rivière Koksoak, l'intrusion des eaux subarctiques relativement plus riches de la baie d'Ungava plus en amont ne peut que provoquer un enrichissement pour la production estuarienne.

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ANALYSIS OF ENVIRONMENTAL IMPACTS OF THE YANGTZE RIVER WATER DIVERSION PROJECT

DAPEI WANG and BARRY J. ADAMS*

ABSTRACT

The major environmental impacts of the East-Route Yangtze River Water Diversion Project (YRWDP) in China are discussed in this paper. Two of them, the induced secondary salinization of irrigated farmland in the North China Plain and the impact of the project on the scarce local power supply, are of primary importance for success or failure of the project. Other impacts include the inducing of further seawater intrusion in the estuary and influences on the aquatic environment and fisheries.

The analysis of the environmental impacts of YRWDP leads to questioning the justification of the project. While the development of northern China is heavily limited by the shortage of natural water supplies, the Yangtze River Water Diversion Project appears to be an economically costly and environmentally risky plan for solving the problem. An alternative plan for overcoming the water shortage in northern China is presented.

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INTRODUCTION

Large-scale interbasin water transfer is often regarded as an effective means of supplying water to arid regions. This idea is indeed attractive in promoting the social and economic development of regions where the development is heavily limited by the shortage of natural water supplies. However, the advantages of water transfer projects are attained only if certain social and environmental costs are sacrificed.

Interbasin water transfer will result in complicated environmental impacts, including physical, chemical, ecological, economic, and social ones, among others. Both positive and negative consequences to the society and the environment may result. To properly evaluate a water transfer project, these impacts should be carefully identified and estimated, and detailed quantitative analyses should be performed whenever possible. This is a great challenge to water resources engineers and environmental scientists, since many of the impacts are difficult to analyze or are even intangible.

This paper analyzes the major environmental impacts of the East-Route Yangtze River Water Diversion Project in China. Such an analysis is intended to reveal the possible consequences of the project and to examine means of solving these problems which may be caused by the implementation of the project. Based on the analysis, some general comments on this project are made.

SYSTEM BACKGROUND

The North China Plain, including Metropolitan Beijing and Tianjin, covers an area of 300,000 square kilometers with a population of 200 million people. This area suffers serious water shortage. It contains some 20% of the nation's farmland but only less than 10% of the surface water resources. The annual precipitation is only 600-800 mm. Groundwater is heavily overdrawn in this area. The social and economic development of this region is heavily limited by the shortage of natural water supply.

South of the Plain, the Yangtze River basin is rich in water resources and is capable of providing considerable amounts of water to meet the demands of northern China. Interbasin water transfer from the Yangtze River basin to northern China has been regarded as a logical solution for supplying water to the arid North China Plain since the 1950's. There were two alternative plans for the Yangtze River water diversion project: the central-route plan and the east-route plan (Yiao and Chen 1983).

The Central-Route plan would divert water from the proposed Three Gorges reservoir on the middle reach of the Yangtze River to Beijing with a canal along the west edge of the North China Plain. This plan has been postponed due to the massive capital costs and other issues concerning the proposed Three Gorges Dam.

The East-Route Yangtze River Water Diversion Project (YRWDP) is being undertaken to supply northern China with water from the lower reaches of the Yangtze River, as shown in Fig. 1. A large quantity of water (up to 1,000 m^3/s) will be diverted from the Yangtze River near its estuary, raised 40 m through 14 massive pumping stations and transported 1,150 km northward to Metropolitan Tianjin through a river-canal complex. The water diversion closely follows the Grand Canal built in the seventh century and passes through the eastern part of the North China Plain.

The construction of the first phase of the project, diverting water from the Yangtze River to the south bank of the Yellow River, began in 1984 and is scheduled to be completed by 1990 (China Pictorial 1984). The design details of the East-Route Yangtze River Water Diversion Project are given below (Yiao and Chen 1983).

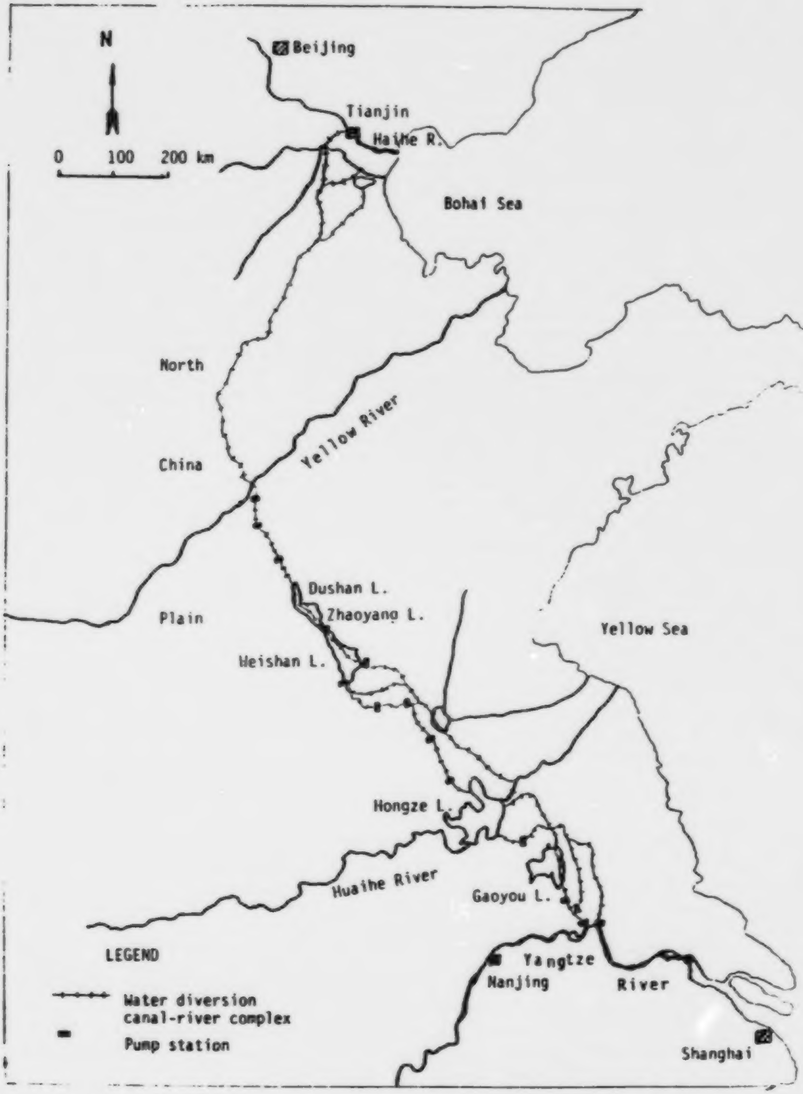
The average annual water diversion is 14 billion cubic meters, among which 15% (2.7 billion cubic meters) will be used for domestic and industrial water supply and the other 85% (11.3 billion cubic meters) will be used for the irrigation of about 4 million hectares of farmland. The domestic and industrial water demand is quite stable while the irrigation water demand is concentrated in the months from January to April and is subject to uncertain variation.

A series of lakes forms part of the diversion route and acts as regulation storage for system operations with a total active storage capacity of some 6 billion cubic meters.

The intake design flow rate is 1,000 m^3/s and the design flow rate of the conduit crossing the Yellow River is 600 m^3/s. The total installation of the pump stations is about 1,000 GW and the total pumping head is 65 m. The estimated annual energy consumption for the system operation is from 3 to 5 billion KWh.

The major environmental impacts of the project are discussed in this paper. Two of them are of primary importance to the success or failure of the project. These impacts are the induced secondary salinization of irrigated farmland in the North China Plain and the impact of large power consumption for system operations on the scarce local power supply.

Other environmental impacts of the project are also discussed in the paper, although they may not be as critical as those mentioned above. These impacts include the inducing of further seawater intrusion at the Yangtze River mouth and the influence on the aquatic environment and fisheries of the Yangtze River and other lakes along the diversion canal.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Hongze L.
Huaihe River
Gaoyou L.
Yangtze
River
Nanjing
Shanghai
LEGEND
Water diversion canal-river complex
Pump station

Fig.1 SKETCH MAP OF THE YANGTZE RIVER WATER DIVERSION PROJECT

IMPACT ON SECONDARY SALINIZATION OF FARMLAND

One of the primary objectives of the project is to provide additional irrigation water for the North China Plain. However, this project may also induce secondary salinization of irrigated farmland. The mechanism of the potential salinization is analyzed and a quantitative prediction of the salinization damage is presented. Methods for controlling salinization are also suggested.

The North China Plain is an alluvial plain and the soil in this area is potentially easy to salify. The total cultivated area in the Plain is about 18 million hectares, of which 15% (some 2.7 million hectares) is saline-alkali soil and another 25% (some 4.5 million hectares) is potentially saline-alkali soil. The groundwater beneath the Plain is saline and alkaline with an average mineral concentration of 2 to 5 g/l and with a water table depth of 2 to 4 m. Raising the groundwater table level will induce salinization of the farmland.

In the late 1950's, many small reservoirs were built in this area to store surface runoff and farmlands were irrigated by flooding, but without proper drainage systems. The seepage from the reservoirs and irrigated land raised groundwater levels and consequently caused salinization of the farmland on a large scale. During that time, the area of saline farmland increased by 140% and caused severe damage to agriculture.

The process of seepage, elevation of groundwater table and subsequent salinization of the soil is a very likely outcome of implementing the YRWDP project. The elevation of groundwater table levels could result from two mechanisms and consequently cause salinization of the farmland in this region.

The first mechanism is due to the infiltration of irrigation water through the soil. Based on the current local irrigation practices (eg., irrigation performed mainly by flooding, low irrigation application efficiencies and poor management of the irrigation system), a large fraction of the irrigation water would infiltrate the soil. The vast quantities of additional irrigation water that are planned to be diverted to the Plain would inevitably raise the groundwater table in this region.

The second mechanism originates from the canals and channels being built for the water diversion and distribution systems. The natural drainage of groundwater in the Plain is from west to east and the water table depth in this area is from 2 to 4 m. The water diversion canal crosses the eastern portion of the Plain and would interfere with the natural drainage route of groundwater, as shown in Fig. 2. Moreover, the seepage directly from canal and channels would raise the groundwater level particularly along the canal and channels to form underground water dams, as shown in Fig. 3. These underground water dams would also retard the natural drainage of groundwater. The effect is to cause the raising

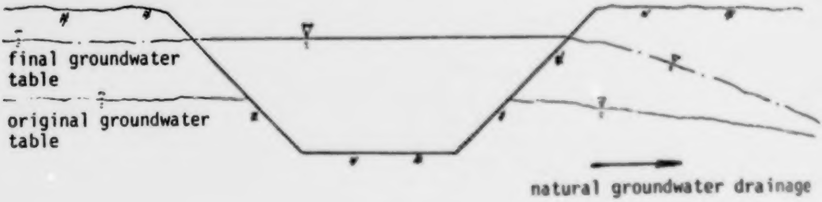
final groundwater table
original groundwater table
natural groundwater drainage

Fig. 2 Interference on natural groundwater drainage from water diversion canals

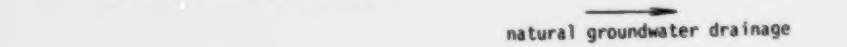
final ground-water table
seepage water table
original groundwater table
natural groundwater drainage

Fig. 3 Interference on natural groundwater drainage from canal seepage

of the groundwater table in the entire Plain and to increase the accumulation of salinity in the groundwater.

The raising of the groundwater table would consequently cause salinization of soil in the Plain. The situation of the 2.7 million hectares of saline-alkali farmland would become worse and the 4.5 million hectares of potentially saline-alkali farmland would salify. The expected damage to agricultural production would be massive.

Some methods are suggested for controlling this salinization of soil. One method is to set the canal water level below the local groundwater level. It requires deepening and widening the canal and would increase the construction costs of the project. It would also result in degradation of the quality of diverted water due to the entrance of saline and alkaline groundwater into the canal.

A more effective method of controlling soil salinization is to improve the local irrigation practices so as to decrease the deep infiltration of irrigation water. This would require a change in irrigation pattern from irrigation flooding to more efficient sprinkler irrigation or other more advanced methods, and the enforcement of improved irrigation system management. Such an improvement requires long-term efforts to equip and train the local farmers, but it is an effective means for controlling soil salinization.

Moreover, if the improvement of local irrigation practices, as well as the efforts to convert the local agricultural production into a lower water consuming pattern and to implement mandatory management to allocate the local water resources in a more efficient manner were successful, the necessity of the interbasin water transfer project could be eliminated or postponed.

IMPACT ON LOCAL POWER SUPPLY

The average annual water diversion of the project is 14 billion cubic meters. The system operation requires pumping a large amount of water (up to 1000 m^3/s) against a high head (up to 65 meters). The estimated annual energy consumption for system operation is from 3 to 5 billion KWh.

The pump stations are to be located in Jiangsuo Province and would consume a significant fraction of the local power system capacity. Unfortunately, this area currently suffers the most serious power shortage, and such a shortage cannot be overcome in the foreseeable future. This area is the most productive area in China. The local industrial production potential has not been fully realized because of the power shortage. It is estimated that the industrial production of the region could be increased by 30% if sufficient power was provided.

The large power consumption for operating the project would aggravate the local power shortage. The opportunity costs of power consumption for operating the project would be very high (James and Lee 1971). Such high operating costs are unacceptable. It is thus questionable whether the water diversion project can be justified on an economic basis.

IMPACTS ON THE YANGTZE RIVER ESTUARY

The impacts of the YRWDP on the Yangtze River estuary include further seawater intrusion in the estuary and the acceleration of sediment deposition at the river mouth.

Seawater intrusion in the Yangtze River estuary significantly degradates the quality of domestic, industrial and agricultural water supplies of Metropolitan Shanghai and its environs. Current water quality management criteria require the concentration of chloride ion in water be less than 250 ppm for domestic and industrial water supplies and less than 600 ppm for irrigation (Sun et al 1983). However, seawater intrusion in the estuary during periods of low streamflows in the Yangtze River can cause the concentration of chloride ion in the local water supplies to exceed 1,000 ppm which would affect the health of the consumers and bring about economic losses.

The streamflow rate of the Yangtze River is the main factor affecting seawater intrusion in the river estuary. During the dry season (i.e. from December to March), in which the average monthly flowrates of the Yangtze River are below 16,000 m^3/s, seawater intrusion in the estuary is significant.

The water diversion project requires withdrawing a large quantity of water (up to 1,000 m^3/s) from the Yangtze River near its estuary. The demand for the water diverted to northern China is concentrated in the period from January to April when the flowrates of the Yangtze River are their lowest. Investigations (Sun et al. 1983) indicate that when flowrates of the Yangtze River are lower than 16,000 m^3/s, diverting Yangtze River water at a rate of 1,000 m^3/s would cause the time over which the concentration of chloride ion in the estuary exceeds 500 ppm to be increased by 35%. This indicates that seawater intrusion in the estuary would be significantly increased.

Seawater intrusion in the estuary would also accelerate the sediment deposition at the river mouth and cause the deposition to occur further upstream. Sediment deposition damages navigation in the Port of Shanghai, the most important port in China.

The effects of water withdrawal on seawater intrusion in the Yangtze River estuary can be partly alleviated through the proper operation of the project. The lakes along the diversion route provide a large active storage volume of some 6 billion cubic meters in total for regulating the system operations. The withdrawal of the Yangtze River water at the intake can thus be regulated. When the flowrates of the Yangtze River are lower than 16,000 m^3/s, the water demands of northern China can be supplied by the water stored in the lakes, and the withdrawal rates at the intake can be reduced or even eliminated during these periods.

IMPACTS ON THE AQUATIC ENVIRONMENT AND FISHERIES

Water withdrawal from the Yangtze River near its estuary reduces the streamflows of the river and changes the hydrologic environment in the estuary. Consequently, it affects the aquatic environment and negatively influences the fisheries in this area. However, investigations (Yiu 1983) indicated that these influences are insignificant.

The water diversion project utilizes a series of lakes as portions of the diversion route and as regulation storage for the system operations. The water levels of the lakes would increase by 0.5-1.5 meters, on average, and fluctuate intensively due to the requirement of system operations (Yiao and Chen 1983).

As a result of this utilization, the aquatic environment in the lakes would be impacted significantly. The aquatic growth and organisms would decrease greatly, the nutrient water in the lakes would be diluted and the water temperature would decline. These changes would degrade the environmental conditions for the fishes with larger body size and greater economic value, which currently constitutes the major fishery of the lakes, and promote the growth of the fishes with smaller body size and less economic value (Yiu 1983). The latter species may become dominant in the lakes, replacing the former species. Such a change would damage the fishery of the lakes. However, this economic loss is insignificant in comparison with other economic benefits and costs of the project.

SUMMARY

The East-Route Yangtze River Water Diversion Project (YRWDP) of China is outlined in this paper. The major environmental impacts of the project were briefly analyzed. Two types of impacts are of primary importance to the success or failure of the project. These impacts are the induced secondary salinization of irrigated farmland in the North China Plain and the impact of large power consumption for the project operations on the already strained local power supply.

The analysis of the environmental impacts of YRWDP leads to questioning the justification of the project. While the development of northern China is heavily limited by the shortage of natural water supplies, the Yangtze River Water Diversion Project appears to be an economically costly and environmentally risky plan for solving the problem.

Based on the analysis, an alternative plan is proposed for alleviating the water shortage in the North China Plain. This alternative plan consists of improving the local irrigation practices, converting the local agricultural production into a lower water consuming pattern and implementing management policies to allocate the local water resources in a more efficient manner. If more effective management and utilization of the local water resources is implemented, the necessity of the interbasin water transfer project could either be eliminated or at least be postponed.

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ON SOME ENVIRONMENTAL IMPACT PROBLEMS OF LARGE WATER PROJECTS IN CHINA

Dr. Shen Ganqing[1]

ABSTRACT

There is a long history of water diversions in the People's Republic of China, and profound recent developments will result in significant new water diversions. This paper briefly outlines some major projects, the principal environmental concerns and new approaches to the evaluation of complex engineering, economic, social and environmental considerations. Of particular interest are the South-to-North Diversions which are so important to PRC goals of increased gross national product and solving important water shortages in Northern China.

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INTRODUCTION

China is rich in water resources with numerous rivers in its vast territory. Water resources projects go back to before the Qing Dynasty (221-207 BC). The famous Dujiangyan Project was built in Guanxian County in Sichuan Province in 250 BC. The Linggu Canal, connecting the Yangtze River water system with that of the Pearl River, was completed in 219 BC. And the Grand Canal, from Beijing to Hangzhou, was constructed during the period 1271-1368 AD.

Since the founding of the Peoples Republic of China (PRC), China has made great achievements in water conservancy works, including 86,880 reservoirs and 6.4 million storage ponds; 2193 MW of hydropower; 160,000 km of dykes; and 100,000 km of river channels and waterways improved for navigation, etc.

As water projects, especially the large ones, can effect the physical, biological and human systems in many different ways, and since these effects may either be beneficial or adverse, the water projects may be called ecological projects.

Since the 1970s, quite a number of EIS or EIA's have been prepared for existing large water projects (either under construction or planned), such as Sanmenxia reservoir on the Yellow River, Xinanjiang reservoir on the Zhijiang River, Gezhouba project and Three Gorge project of the Yangtze River, Danjiangkou project on the Han River, and the South-to-North water transfer project. Utilizing this experience, rules were drawn up in 1982 and a "draft regulation" prepared in 1985 for the formulation of EIA's for water projects.

In the case of interbasin water transfer projects, the environmental impact assessment focusses strongly on the ecological changes of the associated water exporting region, water transfer region and water importing region. Our current experience includes several projects already built, such as the LuanHe-Tianjin and the Biliu He-Dalian water transfer projects; and projects in planning, the main ones of which are South-to-North water transfer projects (East Route and Middle Route) and the Yellow River-Qingdao water transfer project. Based on this experience, the main environmental problems might be summarized as follows:

1. Exporting region
   - lower river navigation channel
   - water temperature increases
   - seawater intrusion in the river estuary
   - coastal ecosystem
   - hydrological regime and climate

2. Transfer region
   - ground water table
   - drainage system
   - aquatic ecosystem of associated lakes and reservoirs
   - propogation of water associated diseases
   - hydrological regime

3. Importing region
   - salination of soil
   - ground water
   - hydrological regime and climate
   - propogation of water associated diseases

In addition, there may be impacts on water quality, other flora and fauna, and economic and social effects for all water exporting, transfer and importing regions.

Unlike the interbasin water transfer projects of some other countries, China's water exporting, transfer and importing regions are mostly in the highly populated industrial and agricultural areas. For this reason the environmental impact assessments have become very important.

Schistosomiasis

A particular problem associated with South-to-North Diversions is schistosomiasis. Before the founding of the PRC, the schistosomiasis disease had been actively transmitted in a large area around the Yangtze River. It was endemic in 11 of the 30 provinces of China. It was not only a social problem, but also a major threat to economic development at the national level. Hence, it is of deep concern in the South-to-North water transfer projects, because of the fear that schistasomiasis may migrate northwards with the transfer of water. The key lies in whether the host snails will move north with the transfer of water. According to special scientific research work and observations of the behaviour and ecology of the host snails carried out at experimental sites in the northern region which are currently (and historically) without the host snail (Jiangsu Province), the northernmost point of snail distribution is Baoying County, Jiangsu Province (35° 15'N)

South-to-North Diversions

Two of the principle schemes under the South-to-North Diversion transfer plans are the East Route which generally follows the route of the Grand Canal system, and the Middle Route which will eventually originate from the Three Gorges Project. Both schemes will transfer Yangtse River water north to the Beijing/Tianjin area, and allow further transfer to northeast China. I will briefly address the Middle Route, as I am most familiar with this scheme.

The Three Gorges project is the largest and best known construction project of China. The Three Gorges Project, comprising Qutang, Wuxia and Xiling Gorge, about 200 km long, provides several dam sites for this multi-objective large water resources project.

Early reconnaissance and planning for such a project was carried out by Chinese engineers, including the author, and goes back to the 1930s and 1940s. The US Bureau of Reclamation engineers proposed a 10,560 MW scheme in 1944.

After the founding of the PRC, comprehensive planning, feasibility study and design, including an EIA, were prepared by Chinese engineers and scientists. The dam site finally adopted is located at Sandouping, 40 km upstream of the almost completed Gezuouba project. Using the 180 m head scheme as an example, the project will control a drainage area of 1 million km^2 (55% of the total catchment of the Yangtze River), with a reservoir capacity of about 20 billion m^3 (1/23 of the average annual runoff), and provide huge socio-economic benefits from flood control, hydropower, navigation and tourism. In addition, it will also bring environmental impacts and ecological changes.

We have exerted our utmost effort in preparation of an EIA for the adopted schemes of the project. The environment and ecology associated problems have been shared between 48 research institutes and departments, organized by Yangtze River Basin Planning Office. Extensive investigations and evaluations have been carried out, including the adaption of a new modified matrix method in order to allow the identification of effects that are indirect, of higher order and dynamic in character.

The main environmental problems of the Three Gorges Project mentioned in the report, prepared in March 1985, are:

1. Natural environmental aspects

   - hydrological regime
   - local climate
   - water quality
   - water temperature
   - reservoir sedimentation
   - lower river erosion
   - induced earthquake and landslides
   - land resources
   - forestation
   - flora and fauna
   - fishery

2 Socio-economic aspects

   - inundation of reservoir region
   - migration and resettlement of population
   - historical and archeological places and sites
   - urban and industrial development
   - tourism and recreation
   - changes in agriculture production and supply
   - socio-economic problems between the workers and the resident population

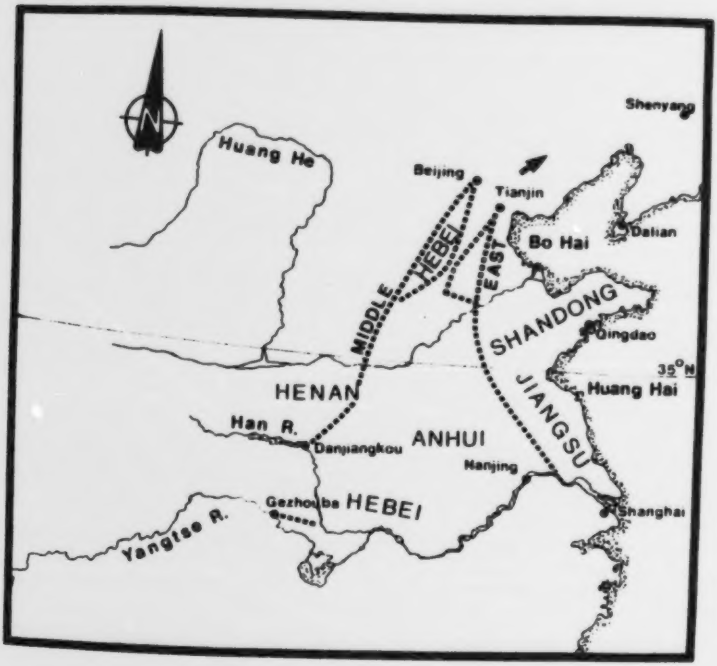
3. Human health aspects

   - schistosomiasis
   - malaria problem
   - other water related diseases

4. Natural environmental and socio-economic aspects during the construction stage

Once the Three Gorges Reservoir is built, water will be diverted from it, according to the preliminary studies of the Middle Route schemes of the South-to-North water transfer projects which were carried out as early as the 1950s. In these schemes, the water of the Han River may first be diverted northward from the Danjiangkou Reservoir.

The main trunk canal for diverting the Han via the Danjiangkou Reservoir will be 1,265 km, of which 481.5 km are south of the Yellow River, 6.5 km in the section crossing the Yellow River, and 777 km north of the Yellow River. The amount of water in the transfer declines gradually from south to north, with 1200 cms at the diversion canal headworks, 800 cms at the Yellow River crossing, 680 cms entering Hebei province, and 120 cms entering Beijing. The proposed Middle and East Routes are shown in Figure 1.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Tianjin
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Huang Hai
HENAN
Han R.
Danjiangkou
ANHUI
JIANGSU
Nanjing
Shanghai
Gezhouba
HEBEI
Yangtse R.

FIGURE 1: Location Map; Eastern part of the Peoples Republic of China

Project Evaluation

Development of projects, such as those mentioned above, are an integral part of our ambitious target to quadruple China's gross national product by the year 2000. To plan our water resources and environment we are investigating the application of techniques such as entropy, fuzzy logic and economic decision-making, especially for large multi-component projects.

For a large-scale system the entropy approach may be expressed as:

$$\Delta S_{\text{large system}} - \Sigma | \pm \Delta S_{\text{subsystem}} | = \text{min}$$

In general, the economic approach might include: activity analysis, quantification of environmental impacts, moneterization of the quantified impacts, and overall evaluation of the moneterized impacts. Thus, the total net benefit of the water projects could be calculated as returns, minus costs, minus the value of the moneterized impacts. The moneterization techniques have been applied for evaluating environmental impacts of China's South-to-North water transfer project (East Route), the Water Diversion Project from Yellow River to Qingdao - a famous coastal city of Shandong Province. More recently, shadow pieces and opportunity cost concepts have been introduced.

The application of fuzzy logic is still developing. However, in many comprehensive and integrated projects the basis for assessments and decisions is often an incomplete data set which is interpreted using empirical methods. In such situations, it is misleading to imply a level of precision that is inconsistent with the methods and data. It is more reasonable that the quantification of certainty be linguistic instead of numeric. Fuzzy logic is a type of logic using graded or qualified statements rather than ones that are strictly true or false, and rather than answers that say 'yes or no' provides a systematic basis for quantifying uncertainty due to vagueness and incompleteness of the information in the context and knowledge base. For this reason we think this approach could be very useful.

Summary

We are carefully studying and testing techniques which help us integrate complex concerns, extensive data systems, multiple resource use concepts, and complex projects to facilitate rationale decision making. At present we are utilizing approaches to achieve integrated planning and management for river environment and development goals. Consistent with our laws for environmental protection (1979) we have established a broad network of environmental agencies and considerable research into our environmental interests.

In a word, Man is both creator and moulder of his environment, and large water projects demonstrate Man's interference with nature and also his wish to contribute to its formation. So long as we do some serious study of and learn from the relationship between water resource development and the environment in the past, we can manage water resource development and water projects wisely with a view to enhancing environmental quality and obtaining maximum economic, social and environmental benefits as a whole. We firmly hold that there are no insurmountable problems in achieving the target of productive harmony between Man and environment, so we are not biased against any type of water resource project.

Nothing is hard in this world, if we dare to scale the heights (rien d'impossible au sein de l'univers, pourve qu'on ose escalader la cime). But the conclusion is that we must treat environment as a critical dimension of large water projects rather than an externality.

SESSION E

INTERBASIN TRANSFER OF WATER:

BIOLOGICAL ISSUES

Moderator: Mr. V.G. Bartnik

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ECOLOGICAL IMPACTS OF THE GRAND CANAL SCHEME ON JAMES BAY

PAUL HACKL and GEORGE MULAMOOTTIL[1]

ABSTRACT

The Grand Canal Scheme proposes to dyke the mouth of James Bay in order to trap vast quantities of fresh water. The bay will change rapidly from salt water to fresh water. This may result in problems of adaptation, especially for the animals. It is possible that regional extinction of some species will occur. Potential alterations in the species composition and habitat may cause major changes in the food chain relationships. The inflow of nutrients is expected to enrich the freshwater lake. The intrusion of salt water will initiate meromoxis in the lake.

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INTRODUCTION

The vast quantities of fresh water available in Canada have attracted American interest for many years. The concept to transfer an unused portion of this valuable resource to the water thirsty regions of North America has been suggested many times (Howe and Easter 1971). Canadian interest in water transfer is evident from the recent award of a federal research grant to the Grand Canal Company (Nikiforuk 1986). This paper examines the potential impact of the Grand Canal on James Bay and its environs.

The Grand Canal Scheme proposes to dyke the mouth of James Bay to establish a fresh water lake. A portion of the fresh water contained in this impoundment could be transferred to the Great Lakes through a series of canals. The excess water held in the Great Lakes could then be channelled to the arid regions of the continent (Kierans 1985).

The available information on the nutrient dynamics, food chain relationships and use of the area by migratory and resident populations of animals within James Bay is fragmentary. The Hudson Bay and James Bay environments have remained, until quite recently, an area of little biological interest. Detailed ecological research in the James Bay area should be initiated to assist in impact analysis for any major projects.

This paper will focus on the potential impacts of the Grand Canal Scheme on the ecology of James Bay based on a literature survey and our understanding of aquatic environments. A brief description of the existing conditions of James Bay will be attempted. The potential changes to these conditions as a result of alterations in the current conditions of the Bay, ice regime and other physio-chemical parameters will then be examined.

PRESENT ECOLOGY OF JAMES BAY

The rivers flowing into James Bay carry approximately 4.2×10^7 metric tons per year of sediments as clay and silt (Kranck 1982). A large portion of this sediment remains suspended in the water and shows a gradient (50 to 5 mg/L) from south to north (Kranck 1982). The rivers flowing from the west coast of James Bay contain significantly more sediments than the rivers which flow into the Bay from the east (Kranck 1982). The currents of the Bay transport large quantities of these sediments around and out into Hudson Bay, thus reducing the accumulation of suspended sediments in James Bay.

Saline water from Hudson Bay enters James Bay through the west side. It moves to the south end of the Bay and then to the east coast and back into Hudson Bay creating an anticlockwise circulation

(Prinsenberg 1982). This circulation pattern is driven by the Coriolis force and the density gradient present between James Bay and Hudson Bay.

The vast quantities of fresh water flowing into James Bay create an estuarine environment. This estuarine zone has a high level of productivity due to its ecotonal characteristics.

James Bay has a long period of ice cover, lasting nine months, due to the subarctic location. The breakup of the ice in spring is influenced by both the influx of water from the rivers flowing into the Bay and the pressure of the Hudson Bay ice pack (Stirling and Cleaton 1979).

A shore lead, a narrow channel of open water, is found along the coast of the Bay throughout the winter, as well as across the mouth of the Bay. An increase in primary productivity occurs due to the greater availability of sunlight associated with the leads. The primary production of the James Bay ecosystem is controlled by autotrophic forms, dominated by phytoplankton. The photosynthesis and production of organic matter by the phytoplankton form the basis of the food chain in James Bay. There are approximately 235 species of phytoplankton in Hudson Bay (Beals 1968). The number of species to be found in James Bay is expected to be the same as in Hudson Bay because of the circulation between the two bays.

The invertebrates of James Bay have a high species diversity and biomass. They are found in all parts of the Bay and form the food source of many vertebrates living in the region (Dunbar 1951). The invertebrates are mostly dominated by crustaceans, molluscs, sponges and worms (Dunbar 1951).

There is a great diversity of fish species within the Bay. A large part of the fish population are slow-growing benthic feeders (Dunbar 1951). A number of anadromous fish species, such as Atlantic salmon, are also found in the Bay. The phytoplankton, zooplankton and benthic invertebrates, along with smaller fish make up the food supply of the larger fishes of James Bay.

The reptiles and amphibians of James Bay are not found in great numbers and are restricted to the less saline coastal marshes. Only three species of snakes and ten species of amphibians are found in this region. This is primarily due to the short summer to which only a few of these animals are able to adapt (Beals 1968). These animals prey on small invertebrates and are, in turn, eaten by fish, birds, and small mammals (Hackl 1987).

The shoreline of James Bay is an important nesting and staging area for the migratory birds of the Atlantic and Mississippi flyways. The macrophyte productivity in these marshes is high during the summer months (Thomas and Prevett 1982). Large numbers of small fishes and aquatic invertebrates are present providing a rich food supply to the numerous species of shore and water birds which return each year (Ross 1982).

The mammals of this region are highly adapted to survival in a cold marine environment. Thick subcutaneous fat layers or heavy fur pelts serve as insulation in the icy waters. This group includes polar bears, beluga whales, walruses, ringed seals, harbour seals and bearded seals. In the winter months these mammals tend to congregate along openings in the ice cover of the Bay, known as leads. The leads provide an air-water interface, allowing the seals and whales to breathe. Seals tend to haul themselves out onto the ice around leads and serve as an important food source for polar bears. The whales and seals feed upon the fish and invertebrates of the Bay (Hackl 1987).

IMPACT OF THE GRAND CANAL SCHEME

The potential effects of the Grand Canal Scheme will be discussed in relation to the physical, chemical and biological conditions of James Bay.

Physical and Chemical Conditions

The Grand Canal Scheme would prevent the movement of the waters of Hudson Bay into James Bay and would significantly diminish or stop the circulation pattern. A generally weakened circulation will assist the formation of a stronger thermal stratification in the Bay and will prevent complete vertical mixing. The dyking will eliminate tidal movemnts and water level fluctuations. The concentration of suspended sediments in James Bay would increase as a result of the reduced circulation. The increased suspended sediment will decrease light penetration and this will reduce the depth of the euphotic zone. In addition, there would be an increase in the accumulation of organic allochthonous materials due to the decreased circulation (Baxter and Glaude 1980).

Ice thickness will increase over the Bay due to the decreased salinity of the water, allowing earlier ice formation. A later spring thaw would result, reducing the period of open water (Baxter and Glaude 1980).

There will be saltwater intrusion into James Bay which is common in freshwater lakes of most coastal regions. The movement of salt water into a freshwater lake would initiate the process of meromixis and, with time, establish a meromictic lake. As is generally found in meromictic lakes the water in the bottom regions of James Bay will become anaerobic. A series of chemical changes would then occur resulting in the release of toxic substances, such as ammonia and hydrogen sulphide. During periods of overturn these toxic products will be mixed with the rest of the water column reducing water quality.

Since the waters of James Bay would be impounded the nutrients in the new lake will significantly increase. Elevated levels of phosphorous and nitrogen in the water of James Bay will stimulate phytoplankton blooms.

Biological Conditions

Primary productivity in the bay is influenced by the depth of light penetration (Grainger 1982). Increased turbidity would decrease the depth of the euphotic zone, reducing total phytoplankton production. This effect will, however, be offset by an increase in the level of nutrients in the water.

The salt water marshes of James Bay are maintained in an early successional stage by "pulse stability", produced by the tidal regime of the Bay. There is a rapid cycling of nutrients as a result of the tides, helping to maintain a fertile environment. The coastal salt marshes of James Bay would change to a primarily fresh water coastal marsh. The elimination of the tidal influence will result in a drop in productivity of the coastal marshes. The vegetation of the marsh may also advance into mature successional stages due to the absence of pulse stability (Odum 1971).

Examination of the productivity of new impoundments in arctic and subarctic Canada has indicated favorable results, particularly for primary production (Duthie 1979; Baxter and Glaude 1980). The enrichment of the waters of James Bay will increase the primary productivity. The increase in primary production will increase secondary production in the form of zooplankton populations which graze on the phytoplankton. The increased primary production would also provide more food for benthic invertebrates in the form of dead phytoplankton.

Anadromous and freshwater adaptable fishes are expected to colonize James Bay (Havinga 1959). It is well known that some marine species will be able to adapt to decreased salinity. The milk fish (Chanos chanos) of South Asia is an example of a fish that has successfully adapted from a marine to a fresh water environment with better growth characteristics. James Bay is used by several fish species during different stages of their life cycles. The dyking of the mouth of the Bay will also be a problem for migrating fishes (Havinga 1949), such as char, salmon and cisco.

The waterfowl of James Bay consists of millions of migratory and some nonmigratory birds. Changes in the fish and invertebrate densities would provide a rich food source to the migratory bird populations of eastern North America and South America. The lowered salinity of the marsh would allow the proliferation of stenohaline plants, resulting in an increase in the total biomass and food supply for herbivorous birds (Havinga 1959; Saeijs and Baptist 1977).

The beluga whales of the Bay are highly migratory and may not adapt well to having their movements limited by a dyke between Hudson and James Bays. A decrease in the size and number of ice leads in James Bay would limit the sites used for feeding, breathing and raising of offspring by whales and seals. The reduction in the population of seals will influence the polar bear population since the bears depend on seals as a source of food during the winter. The large polar bear population of James Bay will feel this impact (Milko 1986).

CONCLUSIONS

The Grand Canal Scheme will have a significant impact on the food chain relationships of the Bay. Impoundment of the Bay will lead to an increase in the availability of nutrients, resulting in greater biomass production. With the continued enrichment of James Bay, the system will become eutrophic. The salt water intrusion will create density gradients changing James Bay to a meromictic lake. The combined effects of these two processes are expected to cause deterioration in water quality. The problems associated with the transfer of water of an impaired quality will have to be addressed during the planning phase of the Grand Canal Scheme.

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THE EFFECT OF FRESHWATER DISCHARGE ON THE MARINE ENVIRONMENT

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ABSTRACT

River input has a profound effect on the physical, chemical and biological processes in coastal waters. These effects are not limited to the immediate vicinity of river mouths or estuaries but can extend thousands of kilometers "downstream" in the case of large river systems. A brief review of the nature of these effects is presented including a general discussion of the role of freshwater runoff on circulation patterns, vertical stability of the water column, mixing characteristics, horizontal exchange processes, ice formation, nutrient supply and primary production. Research on the effects of freshwater on the continental shelf waters off eastern Canada is then described. The influence of the St. Lawrence River has been traced, through coastal sea-surface temperature and salinity, southward into the Gulf of Maine while Hudson Bay runoff has been shown to effect the oceanography of the Grand Banks. The relationship between runoff and fish production in these regions is presented. In the last section of the paper oceanographic effects produced by freshwater diversion projects in the Black Sea, San Francisco Bay, and the Eastmain Estuary in James Bay are discussed.

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INTRODUCTION

The flow of freshwater into the oceans has a profound effect upon the physical, chemical and biological processes in coastal waters. Freshwater induces important circulation patterns, affects vertical stability, modifies mixing and exchange processes, and influences nutrient levels and primary production. Particulate organic and inorganic compounds, as well as organisms, carried seaward by river discharge, are incorporated into marine food chains. The seasonal and interannual variability of the inflowing rivers alters the physical and biological characteristics of coastal waters. This includes the fisheries as interannual fluctuations in the yields of certain commercial fish species are found to covary with runoff. These freshwater effects are not limited to an area close to the river mouth but can extend "downstream" over a thousand kilometers in the case of large rivers.

On the one hand the role of freshwater outflow in terms of its influence on the environment and biota of the coastal regions is complex and the details are not well understood; on the other hand, the requirement for hydroelectric power, flood control, and water for agricultural, industrial, and domestic use has resulted in the heightened awareness by oceanographers of the possible important impacts on the marine ecosystem that may result from increased freshwater regulation or diversions (Skreslet et al. 1976; Benson 1981; Skreslet 1986). Certain projects have resulted in major alterations to the natural seasonal discharge cycle while in others the total annual discharge is altered. Such changes can result in significant and sometimes detrimental effects to large areas of adjacent coastal waters. In the past the marine environment was usually not been considered when planning freshwater management projects and water that reached the ocean was considered a "lost" resource (Bourassa 1985). However, effective management of our freshwater resources should include concerns about the marine environment and the increasing interest in large-scale water management projects, as indicated by the topic of this conference, emphasizes the importance of gaining a better understanding of the environmental effects of freshwater outflow on coastal waters and the marine ecosystem.

The purpose of this paper is three fold: (1) to provide a general overview of the influence of freshwater runoff on the marine environment; (2) to discuss the relationships between freshwater runoff and fish production in eastern Canadian waters; and (3) to examine the oceanographic response to several freshwater diversion projects already completed.

FRESHWATER EFFECTS ON THE COASTAL ENVIRONMENT

The addition of freshwater to the ocean creates a succession of physical regimes each with their own characteristic dynamics, circulation and spatial scales. As freshwater enters the sea it initially spreads over saltwater forming a highly stable but shallow brackish layer, known as a river plume. The spatial scales of the plume are typically a few kilometers. Mixing occurs between the freshwater and saltwater mainly at the edges of the plume and eventually produces a deeper surface layer of brackish water. If confined within a narrow estuary or fjord, this surface layer flows seaward with a necessary compensating landward flow in the subsurface layers. Estuaries and fjords have length scales typically of 10 to 100 km and widths generally an order of magnitude smaller. Upon reaching the shelf the surface layer or estuarine plume, with a volume one to two orders of magnitude larger than the river discharge, turns to the right (in the northern hemisphere) under the influence of the Coriolis force. Once on the shelf the low salinity water tends to flow in a relatively narrow band parallel to shore and is called a coastal current. It has along-shelf length scales of 100 to 1000 km and widths on the order of 10 to 30 km. Marginal seas adjacent to coastal currents often exhibit certain estuarine characteristics, but the mean flows are much weaker than coastal currents. Examples of marginal seas include the Gulf of St. Lawrence and Hudson Bay. Their spatial scale is generally on the order of hundreds of kilometers. Not all of the described regimes occur for a given river. Intense tidal mixing may all but eliminate the river plume. Rivers that discharge onto the shelf may proceed from river plume to coastal current directly. Small rivers are unlikely to form coastal currents. The role of freshwater runoff in the dynamics of a particular regime can vary and, even within a regime, the relative importance of runoff differs from place to place depending upon other factors such as the tides, winds, topography and offshore forcing. Therefore, while there is sufficient knowledge of coastal dynamics to describe the general effects of varying river discharge, application to specific regions requires detailed knowledge of the relative importance of these other factors.

One of the major influences of river runoff in coastal regions is on vertical exchange processes. Where the river meets the ocean, the freshwater induces mixing through the creation of current shear, i.e. strong vertical gradients in the horizontal velocity. When the shear is large enough to produce breaking internal waves, salt water is mixed upwards into the freshwater layer, a process known as vertical entrainment. However, beyond approximately 10 river-mouth widths downstream, mixing of freshwater and saltwater is dominated by other processes such as the tides, winds and internal waves. Seaward of this point freshwater acts to increase stability, thereby suppressing vertical mixing and momentum transfer between the surface and subsurface layers. An increase in river runoff generally results in a further increase in stability, less vertical exchange of water, and lower surface layer salinities although the processes are not linear although the processes are not linear.

A second major effect of river runoff is the generation of horizontal circulation patterns. Initially freshwater flows down surface pressure gradients and tends to float on the sea. With the mixing of salt and freshwater, internal pressure gradients are created between the brackish waters and the more oceanic waters offshore. This gradient forces the brackish waters seaward. To preserve continuity a landward flow develops in the lower layer to replace the salt water lost to the upper layer. This two-layer flow pattern is known as estuarine circulation.

River runoff can also lead to the formation of salinity fronts (boundaries or regions of sharp horizontal salinity gradients) through pulsations in the river runoff, gradients in mixing (caused, for example, by spatial variability in tidal currents), or by wind or current generated convergences. Such fronts are typically observed at the seaward edge of plumes and coastal current systems.

Sea ice formation can also be influenced by the presence of fresh water. With increased vertical stability and in the presence of low salinities, ice will form earlier and more rapidly.

Freshwater effects on biological processes in coastal waters are generally indirect, occurring through the influence of runoff on the physical and chemical environments. While our understanding of phytoplankton dynamics are sufficient to provide some insights into the role of freshwater runoff, at the higher levels of the food chain we are not as far advanced. Indeed our lack of adequate basic knowledge governing the distribution, production, survival and growth of fish larvae impedes efforts to determine the precise role freshwater may play in interannual recruitment variability.

The necessary requirements for phytoplankton growth are vertical stability of the water column, sufficient light and available nutrients. All of these factors can be influenced by river runoff. The response is not simple as primary production may be enhanced or suppressed depending upon several conditions. Light reduction from heavy silt loading, prevention of nutrient addition from the deeper saltwater to the surface layer by strong vertical stability, or rapid advection such that the flushing time exceeds the time scale of phytoplankton growth will act to reduce productivity. On the other hand, in river plumes where freshwater and saltwater are actively mixed, primary production is usually high. Fronts associated with estuarine plumes and coastal currents are also regions of increased production. In areas where there are sufficient surface nutrients, vertical stability imposed by runoff helps to maintain phytoplankton in the euphotic zone thereby enhancing production. As in the case of the physical oceanography, while the general effects of freshwater discharge on the phytoplankton may be understood, the specific response to varying runoff depends upon other factors.

Increased primary production can occur through direct nutrient input from rivers carrying industrial, agricultural or urban wastes. In the case of extremely high nutrient concentrations eutrophication (increased productivity) can occur causing oxygen depletion.

The timing of the phytoplankton production can be altered by runoff. Increased vertical stability from high spring runoff can prevent early seeding of the surface mixed layer by phytoplankton cells overwintering in the deep waters thereby delaying the spring bloom. In other areas the vertical stability imposed by the freshwater allows near-surface phytoplankton to remain in the euphotic zone long enough to initiate the spring bloom.

Freshwater runoff also influences species composition of phytoplankton and zooplankton as species are selected for specific environmental conditions. Thus species differences can arise due to seasonality of the freshwater discharge, between different physical regimes (e.g. river plumes, estuaries, coastal currents) and in the variability in river-borne nutrient supplies. The selection process also includes the ability of organisms to maintain a residual population, often in the presence of strong horizontal advection.

Freshwater effects on zooplankton and larval fish are less clearly defined than in the case of phytoplankton; however, some effects have been observed. High zooplankton abundances have been measured in association with high phytoplankton biomass caused by high nutrient discharges from rivers. Freshwater-induced circulation patterns in estuaries and on continental shelves are believed to play a major role in transporting certain zooplankton and larval fish species from their spawning to their feeding grounds. In general our ability to determine the effects of freshwater runoff on the higher levels of the food chain are hampered by our limited understanding of the factors governing their growth, mortality and survival.

FRESHWATER RUNOFF AND FISHERIES

Although our understanding of the mechanisms is poor, there is increasing statistical evidence that freshwater directly or indirectly affects fish populations. The following section discusses the relationship between freshwater runoff and several of the major commercial species off eastern Canada based on research conducted at the Bedford Institute of Oceanography.

Sutcliffe (1972) in a study of a small embayment along Nova Scotia's Atlantic coast observed a direct correspondence between fluctuations in the amount of local freshwater runoff and the rate of primary production. Lacking adequate statistics from the embayment for testing long-term relationships he turned his attention to the Gulf of St. Lawrence. Not only were there long time series records for the Gulf but the freshwater runoff is very large. The St. Lawrence River system alone discharges 424 km^3y^{-1} of freshwater, a quantity greater than the sum of the entire runoff (353 km^3y^{-1}) along the eastern coast of the United States from the Canadian boundary to the southern tip of Florida (Sutcliffe et al. 1976). The influence of the St. Lawrence discharge is traceable throughout the Gulf of St. Lawrence, onto the

Scotian Shelf and as far south as the Gulf of Maine (Sutcliffe et al. 1976). Year-to-year changes in the freshwater discharge or its seasonal pattern can produce measurable effects on the salinity and stratification of the waters downstream. For example, the summer salinities in the surface waters of the Magdalen Shallows are determined by the spring runoff from the St. Lawrence River (Lauzier 1957).

Sutcliffe (1972) investigated the relationship between fish abundance and St. Lawrence River discharge. Quebec landings of halibut, haddock, soft-shell clams, and lobster were all found to be positively correlated with the annual runoff. The maximum correlation coefficients occur when the fish lags the river discharge. The lag time in years is species dependent and is approximately equal to the age at maturity (i.e., the age it enters the fishery). This indicates that runoff affects the fish's first year of life and is consistent with other biological studies that suggest fish abundance is determined in the egg and larval stages. Sutcliffe argued further that, if the St. Lawrence River is primarily influencing the first year of life, then high correlations may result if runoff at critical months is used rather than annual means. This was subsequently shown to be correct with the spring discharge correlating most closely with the lagged fish abundance (Sutcliffe 1973). As a result of the lag times between river discharge and fish, predictions of catch, e.g. Quebec lobster landings, have been made based only on St. Lawrence discharge rates (Sheldon et al. 1982). These predictions have matched closely the actual landings over the last eight years (Drinkwater 1987).

It was originally thought that increased freshwater discharge causes nutrient enrichment of the surface layers through estuarine circulation and mixing (Sutcliffe 1973). The excess nutrients would lead to increased phytoplankton productivity and enhance the survival of larval fish. A more important effect of increased freshwater flow may be to intensify stratification downstream, which causes greater heat retention near the surface and hence higher surface layer temperatures. This, in part, accounts for the close resemblance between St. Lawrence River runoff and coastal sea-surface temperature records (Sutcliffe et al. 1976).

Sutcliffe et al. (1976) showed that the physical effects of the freshwater discharge from the St. Lawrence River was not limited to the Gulf of St. Lawrence but extended beyond to the Scotian Shelf and the Gulf of Maine (Sutcliffe et al 1976). Therefore, investigations into the possible effects of the St. Lawrence River on Gulf of Maine fish stocks were undertaken. Catches of 10 out of 15 commercial marine species of fish and shellfish in the Gulf of Maine showed significant correlation with the St. Lawrence River runoff (Sutcliffe et al. 1977). As in the Gulf of St. Lawrence, maximum correlations occurred when the fish was lagged by a time approximately matching its age at commercial size. While over half of the species in the Gulf of Maine were positively correlated with runoff, four species were negatively correlated. Fish abundance was also related to local coastal sea-surface temperatures, a result that is not surprising given the high correlation between the sea-surface temperatures and the river discharge. The positively correlated species were generally considered to be near the northern limit of their distributional range, while on the other hand many of the negatively correlated species were near their southern limit. If temperatures are warm then it is good for the warm-water species but not so good for the cold-water species.

Having observed the large geographic area over which the effects of St. Lawrence River are felt, Sutcliffe and coworkers investigated another important source of freshwater in eastern Canada--the runoff into Hudson Bay. The total freshwater discharge into Hudson Bay and James Bay is 523 km^3y^{-1} (Prinsenberg 1980), an amount even larger than that of the St. Lawrence system. The peak monthly mean discharge in June can be traced as a salinity minimum down the Labrador Shelf, onto the Grand Banks (Sutcliffe et al. 1983) and apparently onto the southern Newfoundland Shelf (Petrie and Anderson 1983). Sutcliffe et al. (1983) also related the abundance of Atlantic cod stocks on the southern Labrador Shelf and northern Newfoundland Shelf to changes in surface-layer salinity. Correlations between cod and salinity were positive suggesting high salinity (i.e. low runoff) promotes cod production. They argue that tidally-generated mixing within Hudson Strait increases the nutrients and the salinity in the surface waters. These waters are carried by the residual circulation onto the northern Labrador Shelf where the nutrients promote primary production. In the time required for a food chain to develop, the water is advected southward by the Labrador Current; this explains the southward increase in fish concentrations along the Labrador Shelf. In years of high freshwater-outflow from Hudson Bay, the increased stratification suppresses mixing, which reduces nutrients and lowers the salinity of the water on the Labrador Shelf; less food is then available to the cod.

In the studies cited within this section, statistically significant relationships between fish and runoff were established by correlation techniques. Similar results have been observed in other areas (Skreslet 1976; Meeter et al. 1979; Rozengurt et al. 1985). Problems with correlation analysis are well known and caution must be exercised in interpreting, or even accepting, the results. The data sets are relatively short resulting in few degrees of freedom when calculating significance levels for the correlations especially after taking into account serial correlation in the data (Sutcliffe et al. 1977, Drinkwater 1987). One criticism of correlation analysis is that it can produce spurious correlations, i.e. covarying data sets that are totally unrelated. That this is not the case is suggested from the fact that the highest correlations occur for a lag time between runoff and fish catch which generally equals the mean age at commercial size, a finding in agreement with the general belief that survival is most strongly influenced by events in the first year of life of the fish. However, the fish still may not be responding to the freshwater variability but rather another oceanic or atmospheric variable that itself correlates well with runoff (Koslow 1984; Koslow et al. 1986; Sinclair et al. 1986).

Further investigations are required before the actual effect of runoff on fish and its mode(s) of influence are understood. The task is not easy nor will it be accomplished quickly. Fish populations and the factors controlling their variation are many and complex. To determine the role of runoff variability on fish, better understanding of the effects of such factors as fishing, interactions between species, and biological factors are required.

OCEANOGRAPHIC EFFECTS OF FRESHWATER REGULATION

From the above discussions it is clear that freshwater inflow can play an important role in coastal waters and it follows that modifications to the freshwater inflow should result in measurable oceanographic responses. In this section the marine response to changes in freshwater inflow in the Black Sea, San Francisco Bay and the Eastmain Estuary of James Bay are described.

Black Sea

Tolmazin (1985) has described changes in the hydrography of the Northwestern Shelf in the Black Sea, including the Dnieper and Dniester estuaries, induced by inland water management projects. In the 1950s the U.S.S.R. began hydroelectric projects on the rivers flowing into the Black Sea. These were completed in the early 1970s. The large reservoirs that were created caused a loss of freshwater through increased evaporation and a further reduction resulted from increasing consumption by industrial, agricultural and municipal users. The seasonal cycle of freshwater runoff was changed to accommodate hydroelectric production. Water problems were heightened by the intensive use of agricultural chemicals which reached the rivers through runoff and irrigational seepage. Both the quantity and quality of the water deteriorated.

Tolmazin (1985) noted several changes in the adjacent coastal regions. The lowering of the amplitude and the shift in the time of the peak seasonal discharge of the Dnieper River resulted in the low-lying marshes in the Dnieper Estuary not being covered during the period of peak fish migration. The irregularity of the river discharge due to weekly and daily cycles in hydroelectric production produced associated fluctuations in the currents, particulate content and salinity which were deleterious for many of the estuarine species of fish and zooplankton. The average salinity in the Dnieper Estuary increased and there was an extension upstream of the near-bottom salinity layer. The shrinking of the area of fresh and brackish water habitats coupled with diminished reproductive capabilities meant many of the zooplankton and fish species left the estuary. Excessive phytoplankton blooms occurred in the estuary as a result of high nutrient levels carried by the river and derived primarily from agricultural sources. Peak nutrient concentrations increased by a factor of 2 to 8 over normal conditions. Also contributing to the large blooms was the loss of the higher trophic levels which normally grazed upon the phytoplankton. The blooms lead to anoxic (low oxygen levels) conditions. Commercial fishing in the Dnieper Estuary dropped by a factor of 5 and in the Dniester Estuary it all but ended.

The effects of river modifications were not limited to the estuaries (Tolmazin 1985). Increased early summer river discharge generated intense vertical stratification of the water column such that the lower layers in the coastal waters of the Northwest Shelf were nearly isolated from the surface layer. This cut off the oxygen supply to the lower layer and, with increased deposition of organic river-borne material reaching the sea bed, caused hypoxia (extreme oxygen deficiency) and mass mortality in the bottom layers of the Shelf. Although the depletion of dissolved oxygen had been recorded in the precontrol era, the anoxic events and extensive mortality of bottom fauna and flora increased dramatically in the late 1970s and 1980s. This lead to a sharp decrease in catches of fish and invertebrates, such as turbot, flounder and crab, which have remained low.

San Francisco Bay

Extensive modification of the Sacramento-San Joaquin River system, which flows into San Francisco Bay, has taken place over the past several decades. Of the 34 km^3y^{-1} that historically discharged into the Bay, it is estimated that 40% is now removed for local consumption and another 24% is diverted to central and southern California, leaving only 36% entering the estuary (Nichols et al. 1986).

The reduced freshwater inflow into San Francisco Bay has lowered the flushing time of the water in the Bay thereby reducing its ability to rid itself of industrial contaminates (Rozengurt 1983). There has also been a rise in the mean salinity of the Bay and salinity intrusions have extended farther upstream in the Sacramento-San Joaquin Estuary (Rozengurt 1983; Rozengurt et al. 1985). It is estimated that there has been a reduction of 60 to 75% of the 8×10^6 tonnes of sediment discharged annually into the Bay under natural mean runoff conditions (Krone 1979). The most important changes, however, appear to have been on the biological community in the Bay. The adult population of striped bass has decreased by 75% since the mid-1960s (Stevens et al. 1985) and the chinook salmon population declined by 70% since the early 1950s (Kjelson et al. 1982). These declines have been attributed to reductions in the freshwater runoff through degradation of the spawning areas, reduction in their food supply through a general decrease in the biological productivity of the Bay, introduction of river-borne toxic substances, and loss by entrainment in water diversions (Kjelson et al. 1982; Stevens et al. 1985; Rozengurt et al. 1985). A period of extremely low flows in 1976-77 (summer discharges of less than 100 m^3s^{-1}) have highlighted the importance of freshwater on the biology of the Bay. During the summer of 1977 the phytoplankton biomass dropped to 20% or normal levels (Cloern et al. 1983), zooplankton and shrimp abundance decreased (Knutson and Orsi 1983) and the striped bass declined severely (Stevens et al. 1985). The shrimp and bass have remained at reduced levels. The data clearly show that fish production in the Bay depends on a high biomass of primary production which, in turn, requires a minimum of freshwater inflow. This is further supported by high correlations between the mean annual runoff and the commercial catches of salmon, striped bass, and shad for the pre-diversion years of 1915-44 (Rozengurt et al. 1985). The results of Rozengurt et al. (1985) also suggest that to ensure successful commercial landings of the three species approximately 70% of the long-term average runoff must be discharged, i.e. about twice the present levels.

Two mechanisms have been proposed to explain the relationship between the phytoplankton productivity and freshwater runoff. Cloern et al. (1983) suggested that because the estuary is turbid, phytoplankton growth is small in the deeper river channels but relatively large in the lateral shallow embayments where currents are lower and light limitation is less severe. They argue that circulation changes associated with low freshwater discharge causes the suspended particulate maximum to migrate upstream adjacent to the shallow bays thereby reducing the phytoplankton biomass. Nichols (1985) contends, however, that during periods of reduced flow immigrant benthic suspension feeders graze down the phytoplankton. He believes the benthic animals are usually prevented from the high phytoplankton production regions by high winter freshwater flows. Both mechanisms may have occurred simultaneously during 1977. Regardless of the dominant process it appears that the low phytoplankton production was related to the reduced freshwater inflow.

Eastmain River, James Bay

Beginning in July 1980 over 90% of the Eastmain River in James Bay was diverted northward into the La Grande system. Prior to diversion the mean annual discharge of the Eastmain River was near 38 km^3y^{-1} (1200 m^3s^{-1}) with a monthly maximum of approximately 2500 m^3s^{-1} in June and a minimum of 260 m^3s^{-1} in March (Lepage and Ingram, 1986). The mean annual discharge after diversion has been about 2.5 km^3y^{-1} (80 m^3s^{-1}; Ingram et al., 1985).

The changes to the physical regime have been described by Lepage and Ingram (1986). Prior to diversion, the Eastmain was essentially a salt-free estuary and the river water produced an extensive (100 km^2) brackish plume 1 to 2 m deep in the adjacent coastal waters. Following diversion the surface flow in the lower estuary decreased almost 90% from approximately 40 to 5 cm s^{-1}. Saltwater penetrated 8 km upstream of its historical position resulting in a decrease in amplitude and reversal in sign (upstream as opposed to downstream) in the mean currents near bottom. Tidal currents amplitude increased by 75 to 100% at mid-depth approximately 5 km upstream of the mouth, although near-bottom tidal currents decreased. Offshore of the river the salinity increased throughout the summer following the diversion and the amplitude of the semidiurnal salinity variability decreased indicating a smaller freshwater plume. Lepage and Ingram (1986) were able to model the amplitude, location and the temporal variability of the salinity intrusion and showed it was primarily governed by tidal dispersion.

Accompanying the salinity intrusion was a major phytoplankton bloom and a change in the species composition from a freshwater dominated environment to a more marine oriented one (Ingram et al., 1985). The bloom, however, was due primarily to the increased production of a strictly estuarine species and is believed to have resulted from a combination of high nutrient levels, strong vertical stability of the water column, and low surface velocities which would have retained the bloom within the estuary (Ingram et al., 1985). Cause of the high nutrient concentrations that occurred following the diversion is unclear but may have been through advection from James Bay, regeneration from local sediments followed by vertical transport as a result of larger tidal currents or lateral transport of materials resulting from wave erosion on newly exposed river banks as the mean water level decreased by approximately 0.3 m near the mouth of the estuary. Fish larvae characteristic of James Bay and not seen previously in the Eastmain Estuary were observed immediately following diversion (Ochman and Dodson, 1982). Further measurements are required, however, before it can be determined whether these fish species will inhabit the estuary on a permanent basis.

Changes in sedimentation have been discussed by D'Anglejan and Basmadjian (1987). Prior to diversion the strong river currents kept the estuary free of any river-derived solids. After diversion, turbidity increased and sediments began to be retained within the estuary. Large river discharge rates can temporarily flush the salt water out of the estuary carrying with it the suspended particulate material. Deposition is therefore expected to depend upon the spacing between such events as consolidated of deposed muds can occur rapidly. The large reduction in the flow of Eastmain River has resulted in a 10-fold reduction in the annual rate of solid discharge to the estuary and a 25-fold reduction in the rates of suspended sediment transport out of the estuary into James Bay.

Summary

The results from the Black Sea, San Francisco Bay and the Eastmain Estuary have demonstrated measurably changes in the coastal marine environment that can be directly attributed to reduced or modified freshwater inflow. These regions are not unique and many other examples are readily available, e.g. the Nile River (Aleem, 1982), many of the major estuaries in the United States (Mahmud 1985), the Sea of Azov in the U.S.S.R. (Tolmazin 1985; Rozengurt et al. 1985; Rozengurt and Herz 1981), the Santee River in North Carolina (Kjerfve and Greer 1978), the Zambezi Delta in South Africa (Rozengurt and Herz 1981) and the Aral Sea in the central Asian region of the U.S.S.R. (Rozengurt and Herz 1981). Other projects have been proposed that have caused concern. For example in the late 1970s the U.S.S.R. announced a plan to divert up to 400 km^3 yr^{-1} of the water flowing into the Arctic Ocean towards the agricultural regions in the south by the end of the century. Initial investigations, including those by Soviet scientists, suggested possible significant changes especially in the extent of ice coverage and the oceanic circulation in Arctic (Holt et al. 1984; Semtner 1984; Gribbin and Kelly 1986). After a decade of debate the project now seems to be called off although the reasons, be they financial, political or scientific, remain unclear (New Scientist 1986).

Increasing political desire to harness additional hydroelectric power and to ship Canadian water southward (Bourassa 1985) will require important decisions in the coming years. Effective planning of river diversions or other modifications should include an assessment of such activities on the adjacent coastal regions. While the initial assessments have begun in the Hudson Bay area (Prinsenberg 1982, 1983, 1984; Milko 1986) much more basic research is required before quantitative understanding of the effects of freshwater diversion and modification of flow rates on the marine environment will be achieved.

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PACIFIC TO ARCTIC TRANSFER OF WATER AND BIOTA

THE McGREGOR DIVERSION PROJECT IN BRITISH COLUMBIA, CANADA

G.C.Seagel[1]

ABSTRACT

In 1976 the British Columbia Hydro and Power Authority (BC Hydro) initiated a program of studies to determine the environmental effects of a proposal to divert the waters of the McGregor River, a tributary of the Fraser River (Pacific drainage), into the Parsnip River, a tributary of the Peace River (Arctic drainage). The proposal would have required a 140 m high dam on the McGregor River which would have created a 23,500 ha reservoir and overflowed the Arctic-Pacific divide. However, in 1978, as a result of the findings of the environmental studies, BC Hydro suspended consideration of this proposal. Specifically, the suspension was a result of findings that indicated that the development could introduce potentially harmful fish parasites into the Arctic drainage.

This paper outlines the program of environmental studies undertaken for this proposed development. Particular attention is given to the extensive study of the transfer of fish and associated parasites and viruses. There was little in the literature to aid in the planning of such a study and the findings can be of value to others who may have to deal with the question of faunal transfer involving parasites, bacteria, viruses and fish.

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DETOURNEMENT D'EAUX ET D'ORGANISMES DU BASSIN PACIFIQUE AU BASSIN ARCTIQUE

LE PROJET McGREGOR DE DETOURNEMENT D'EAUX EN COLOMBIE-BRITANNIQUE

G.C. Seagel[2]

RESUME

En 1976, suite a une proposition visant a deverser les eaux de la riviere McGregor, tributaire du fleuve Fraser (bassin du Pacifique), dans celles de la riviere Parsnip, tributaire du fleuve La Paix (bassin de l'Arctique), Hydro BC mit sur pied un projet d'etude dans le but de determiner les effets environnementaux que ce detournement pourrait entrainer. La proposition prevoyait la construction d'un barrage, haut de 140 metres, sur la riviere McGregor. Ce barrage aurait cree un reservoir de 23,500 hectares qui aurait deborde la ligne divisoire des eaux du Pacifique et de l'Arctique. Cependant en 1978, apres avoir examine les resultats du projet d'etude, Hydro BC decida de reporter a plus tard toute decision a ce sujet. Les constatations du projet d'etude semblent indiquer que le detournement des eaux pourraient introduire dans le bassin de l'Arctique des parasites de poissons dont les effets pourraient etre nuisibles.

Cet article trace les grandes lignes du projet d'etude et examine plus particulierement le deplacement des poisson ainsi que des parasites et des virus qui leur sont associes. Il existe peu de references, dans la litterature scientifique, qui puissent servir a l'elaboration d'une etude sur ce sujet. Nous esperons que les resultats obtenus pourront aider les chercheurs interesses a la question du deplacement de la faune, et plus specifiquement du deplacement des poissons, de leurs parasites, virus et bacteries.

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INTRODUCTION

British Columbia is Canada's westernmost province. The province's largest river is the Fraser River which has a mean monthly flow of 3430 m^3/sec when it reaches the Pacific Ocean, some 1,300 km from its source. The Fraser River is a major source of salmon and there are no dams or hydroelectric generating stations along the mainstream of the river.

Another major river in British Columbia is the Peace River, which flows from Williston Lake north of Prince George in an easterly direction to the Alberta border where its mean monthly flow is 1,390 m^3/sec. The Peace River then flows north through Alberta to the Great Slave Lake in the Northwest Territories which in turn flows to the Mackenzie River and on to the Arctic Ocean. The Peace River has two major dams with hydroelectricity generating stations, which have a combined generating capacity of almost 3,500 MW.

The Peace River basin (Arctic Drainage) adjoins the Fraser River basin (Pacific drainage) for some 520 km. For many years it has been realized that a dam on the McGregor River, a tributary of the Fraser, would lead to waters of the McGregor overflowing the divide between the two basins. Hence McGregor waters would flow by way of the Parsnip River and Williston Lake into the Peace River instead of the Fraser River.

In the early 1970's, BC Hydro and Power Authority, which is responsible for the provision of electricity to over 90% of the population of BC, gave serious consideration to the concept of diverting water from the McGregor River in order to increase flows in the Peace River and thereby increase the electrical output at the existing generating plants at relatively low cost. BC Hydro found that it would be possible to construct a 140 m high dam on the McGregor River to create a 23,500 ha reservoir which would overflow the divide and cause the McGregor River waters to reach the Peace River via the Parsnip River. A diversion structure would have been provided at the point of overflow capable of passing an average flow of 188 m^3/sec and a probable maximum flood of 4,400 m^3/sec.

It was appreciated that, before the diversion of the McGregor could be regarded as feasible, important environmental questions would need to be answered. Accordingly, in 1976 BC Hydro commissioned a comprehensive program of environmental studies.

The commissioned studies were designed to answer three main questions:

1. What would be the environmental impacts of the dam and reservoir?
2. What would be the environmental impacts of the decreased flows in the Fraser basin?
3. What would be the environmental impacts of the increased flows in the Peace River basin?

In order to answer these questions, specialists were commissioned to report on impacts in the following areas:

- Geology and Physiography
- River Regime and Morphology
- Wildlife
- Social and Economic Concerns
- Forestry
- Recreation
- Land Use
- Water Temperature
- Water Levels
- Water Quality
- Fisheries
- Faunal Transfer

These studies were concentrated on the McGregor River valley, the Parsnip River valley and the Fraser River. The faunal transfer studies concentrated on the Parsnip-Peace basin and the McGregor-Fraser basin and are the focus of this paper.

The studies undertaken led to the suspension of the project in 1978, primarily due to the concern over the transfer of fish parasites from the Pacific to the Arctic drainage.

FAUNAL TRANSFER

Faunal transfer studies were undertaken in response to the initial concern that certain viral and parasitic forms which exist in Arctic drainage would be transfered to the Fraser River with the potential to impact the valued Pacific salmon fisheries.

When environmental studies of the McGregor Diversion project began in 1976, there were few precedents for the design of a detailed program to evaluate the question of faunal transfer associated with a major diversion project. In consequence, and after much consideration, a program was drawn up incorporating a careful literature review, analysis of existing physical and biological conditions, assessment of natural transfer potential, and laboratory analysis of several thousand fish for parasite, virus and bacteria identification. The overall fish study involved the capture or observation of almost 25,000 fish, of which 16,105 were from the Parsnip basin and 8,725 were from the McGregor basin.

The transfaunation concern was addressed in four parts, focussing on fish, bacteria, viruses and parasites.

Transfer of Fish

When considering the transfer of fish, studies investigated historic transfers, potential for natural transfer, man-induced transfer and transfer due to McGregor Diversion project.

It was found that water connections already existed along the Arctic-Pacific divide which allow the movement of fish between the two systems. Under certain physical and hydrologic conditions, similar connections could develop without the project, thereby allowing the capture of headwater fish populations. Water transfer along the Arctic-Pacific divide probably occurs at present due to groundwater seepage and, on a limited basis annually, because of snow melt and surface runoff. The principal sites at which some potential for natural water tranfer exists are the result of forestry and/or beaver activity.

The possibility of accidental introduction of fish species has existed and always will exist. At the same time, the planting of fish from Pacific drainage populations has taken place in Arctic drainage waters of the study area and could continue. If there were no control structures (or ineffective structures) at the Arctic Lake divide, then it was thought that only one of four fish species which have not previously appeared in the Arctic drainage could be transferred to the Peace River drainage, and one species transferred to the Fraser River. Neither the northern pike nor the parasite Trianenophorus crassus were found in the study area,[3] and neither was expected to have access to the McGregor Reservoir.

Transfer of populations of ubiquitous fish species across the divide was not expected to cause a problem. Consequence of the transfer of exotic fish species present in the study area did not appear to be serious, and no major negative impacts were identified. However, it must be remembered that suitable evaluations of the effects of introductions on existing populations are scarce and that hidden impacts may exist. Also, assessments existing to date do not take into account potential disease or parasitological problems connected with the transfer.

Transfer of Bacteria

The only potentially pathogenic bacterium detected was bacterial kidney disease in a rainbow trout taken from the McGregor River and that was made only by microscopic observation. Other organisms isolated were ubiquitous motile aeromonads, myxobacterium, sporocytophaga and pseudomonas species, all considered to be non-hazardous in a wild fish population.

Transfer of Viruses

No viruses were detected in any of the fish specimens. Although IHN virus was not detected it is known to exist in chinnok salmon in the upper reaches of the Fraser River and a potential hazard associated with this virus could occur, although little is known of its presence or absence in the Arctic drainage system.

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[3] Northern pike have recently been reported in Summit Lake, by the BC Ministry of Environment and Parks (August, 1987).

Transfer of Parasites

During the study 78 species of parasites, or higher taxonomic groupings (taxa) of parasites, were recovered from 1489 fish. The 1489 fish examined included 859 fish of 17 species from the Arctic drainage and 630 fish of 16 species from the Pacific drainage. Of the 78 taxa received, 26 were from hosts taken in only one of the two watersheds (10 from the Arctic system and 16 from the Pacific system.

There are difficulties in attempting to analyse or interpret the results of a study of this nature. When working with natural populations, neither total fish populations nor prevalence of disease can be determined with any degree of accuracy; therefore, estimates of adequate samples can only be made in retrospect. Changing environmental conditions must also be taken into account. For example, a change in a single factor such as temperature can have wide-ranging effects on various aspects of the biology of parasites.

From this study, it was concluded that, without minimizing the potential consequences related to transfaunation of the 78 taxa or parasites found, three forms not currently found in the Parsnip drainage (Ceratomyxa shasta, Cryptobia salmositica, and Haemogregarina irkalukpiki) could be expected to pose the greatest threat to the fisheries resources of both the study area and downstream areas. The latter two forms are considered to be of lesser importance, primarily because they both require intermediate hosts and are reported to be less pathogenic. Ceratomyxa shasta appears most problematic since it has a direct life cycle, is highly pathogenic, affects economically important species of fish, and could effect a very large geographic area, that is, the entire Peace-Athabasca-Mackenzie River systems.

CONCLUSIONS

Based on experience with the McGregor Diversion Project, it is suggested that an inter-basin water transfer project entails considerations of a considerably more complex nature than simple impoundment schemes. An inter-basin water transfer project involves the diversion itself, a donor basin and a receiving basin. Factors to be taken into consideration in the decision-making process include the following:

1. The biological assessment ultimately depends upon the adequacy and detail of the assessment of the predicted physical changes. Both the scope of the physical impacts by the receiving waters in the receiving basin, and the impact of reduced flows below the diversion system in the donor basin, require intensive study. At present, forecasts of these impacts are largely judgemental although based on the best expertise and knowledge available.

2. The study of aquatic fauna, especially fish species, their distribution, life cycle, habitat types and response to physical changes, is most important. Often sufficient baseline information is not available and this must be collected before further work can properly proceed.

3. Transfaunation requires knowledge of viral, bacterial and parasitic species present in donor and receiving waters, their life cycle history and their pathogenicity. Generally, the information available is not adequate for a proper assessment of impacts and risks. Assessment of risks to aquatic resources due to transfaunation also requires consideration of mitigative measures and the diversion systems physical behaviour in time and space.

4. Because of the poorly defined risk-assessment methodologies associated with transfaunal studies, the decision-making process is made considerably more difficult. Further work is required to help determine acceptable risk.

5. The degree of human activity and dependence on physical conditions in an area, and the consequent use of aquatic resources, is also important to the study of inter-basin water transfer project impacts. Ultimately, this factor is most crucial in the decision-making process.

Water must be viewed as a multiple-use resource. Inter-basin water transfer projects have indirect effects that can significantly alter or influence human value systems. In light of these complexities it is vital that all such projects be properly documented both before and after implementation in order to build a body of knowledge from which all subsequent projects can benefit.[4]

DISCUSSION

The McGregor Diversion Project study was carried out some ten years ago, at a time when the role of the environmental impact statement was developing and blossoming. Many new data needs were identified, and the need for a framework within which decisions could be made was becoming evident. It is hoped that this conference will emphasize the necessity to address these needs.

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[4] Fisheries and Oceans Canada, reporting on the McGregor Diversion Project in 1986, noted that the cost of studies that might be required to quantitatively address faunal transfer questions would be prohibitive.

I envisage three main foci for future studies relating to faunal transfer, as noted below:

1. Data requirement:
   - on organisms, emphasizing life cycle and habitat, distribution and trends.
   - on direct and indirect pathogenicity.
2. Development of risk analysis techniques.
3. Development of management strategies on a multi-disciplinary and integrated basis, including reference to allowable risk.

SESSION F

INTERBASIN TRANSFER OF WATER:
INSTITUTIONAL ISSUES

Moderator: Mr. Rick Carnduff

Stanley Associates Engineering Ltd.
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INTERSTATE/INTERBASIN TRANSFER OF WATER:

LESSONS TO BE LEARNED

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ABSTRACT

Virginia Beach has grown in 40 years from a town of 22,000 residents to the second largest resort city on the Atlantic Ocean. This growth occurred while Virginia Beach was completely dependent on another city for its water supply. The ever-present threat of droughts coupled with the continuing rapid growth of the area's population necessitated a larger, more dependable water supply.

The search for alternative water supplies resulted in the identification of four possible sources of water. The best alternative was an interstate stream that would require a 60-inch main approximately 85 miles long. The water would pass through five counties and one city and would cross 30 streams and rivers.

The first step in the permitting process was the preparation of an "environmental assessment," which would determine whether the environmental impact of the project was significant enough to require filing a more detailed environmental impact statement. The permitting agency found no significant impact and issued the permit. Three law suits were filed immediately after three years of legal maneuvering, and the judge has just rendered a decision requiring two more studies.

Interbasin transfer of water from an interstate stream is only slightly more complicated than the transfer of water from one basin to another within a state or province. Whether a transfer is sound technically and practical economically is no longer the dominant issue. The legal and institutional problems and people's resistance to sharing their water supply problems are the most significant problems that must be addressed if water is to be transported from areas of surplus to areas of need.

This paper deals extensively with the socioeconomic justification of the project, the environmental impacts, both real and imaginary, and the legal and institutional problems associated with making the transfer a reality.

INTRODUCTION

In the early development of the United States and Canada, the availability of water for transportation and power played a significant role in where people located and commerce and industry developed. The coming of the railroad and the use of fossil fuels reduced the dominate roll water had played in the demographics of the country. The availability of other natural resources and climatic amenities and other factors became much more important elements in influencing where people lived. Thus the increased demand for water in this century has not always occurred where the supply was most available.

The management of a finite resource to meet increasing demand may necessitate the movement of water from one drainage area to another. In the so-called "water rich" areas of the United States, these transfers in the past occurred almost - unnoticed - they were rather small and no hardships where perceived by those in the basin of origin. The remaining water seemed abundant enough to meet existing and future needs. Today the per capita demand has increased and the amount of water to be moved is much larger, so any proposed transfer does not go unnoticed.

Until it is reduced to capture, surface or groundwater, is usually considered a public resource, but the public perceives running water as "their water." Because water is important to everyone, if for only domestic purposes,d it is not difficult for those who oppose any movement of water to generate a large constituency. With a few horror stories they can change the a constituency into a group with mob tendencies. With such emotion, rational considerations often surrender to assertions of "stealing" or a "communist plot."

Virginia Beach's efforts to secure water from the Roanoke River, a stream of North Carolina and Virginia share, show the problems that can beset a community seeking to supplement its water supply from an area of surplus but beyond its political boundaries.

HISTORY OF WATER PROBLEMS

The early history of Virginia Beach gave no indication that it would experience almost exponential growth after World War II. In 1940, its population was a mere 22,584, and today, with a population of more than 324,000, it ranks second to Miami as the largest resort city located on the Atlantic Ocean. Its population is projected to increase to 473,000 by the year 2030. Not only has its population increased, but so have its geographic boundaries. On January 1, 1963, the town of Virginia Beach merged with Princess Anne County to become the city of Virginia Beach.

The water supply for the town of Virginia Beach was a conglomerate of private wells and commercial enterprises until 1923, when it entered into an agreement with the city of Norfolk to provide water to the municipality. Norfolk constructed and still owns most of the water transmission lines in Virginia Beach. The latter is required to pay its prorata share of operation, maintenance, and capital improvement costs of the Norfolk system.

During periods of precipitation, the Norfolk water system has a surface water capacity of approximately 81 million gallons per day (mgd). Of this amount, the system provides 40 mgd for Norfolk residents and 11 mgd for military establishments in the area, leaving approximately 30 mgd available for Virginia Beach. Although Virginia Beach currently uses only 25 mgd, its demand is expected to increase to 34 mgd by 1990. Sometime in the next five years, Norfolk will not be able to meet the water supply needs of Virginia Beach. If a drought as severe as the one in 1980-81 should occur, the total available water supply from Norfolk would be about 59 mgd. That estimate leaves leaves only 8 mgd (23 percent of its projected demand in 1990) available for Virginia Beach, assuming no reductions in use by Norfolk and the military establishments through conservation.

Virginia Beach has recognized, for a considerable amount of time, that the long-term solution to its water problem is to develop its own water supply system because its current use of 25 mgd is projected to increase to 57 mgd by 2030.

SEARCH FOR A SOLUTION

A series of engineering reports has proposed four possible sources of water for Virginia Beach--Lake Genito, Assamoosick Reservoir, Lake Gaston, and an in-town alternative. Six criteria were used to evaluate the various alternatives: quantity; quality; environmental impacts; reliability; cost; and legal, political, and institutional issues. Of the four proposed sources, withdrawal from Lake Gaston on the Roanoke River ranked first in three of the criteria, tied for first in another criterion, and tied for second in the last two criteria.

The Lake Gaston option would take water from a reservoir on the Roanoke River that is owned by Virginia Power at a point on the Pea Hill Creek branch just north of the North Carolina/Virginia border. The water once withdrawn would be transported by a 60-inch water line approximately 85 miles to Norfolk's raw water transmission system and the city of Suffolk. Passing through five counties and the city of Suffolk, the line would cross thirty streams and rivers and be layed for the most part on existing easements for power lines, railroads, and water utilities (see Figure 1).

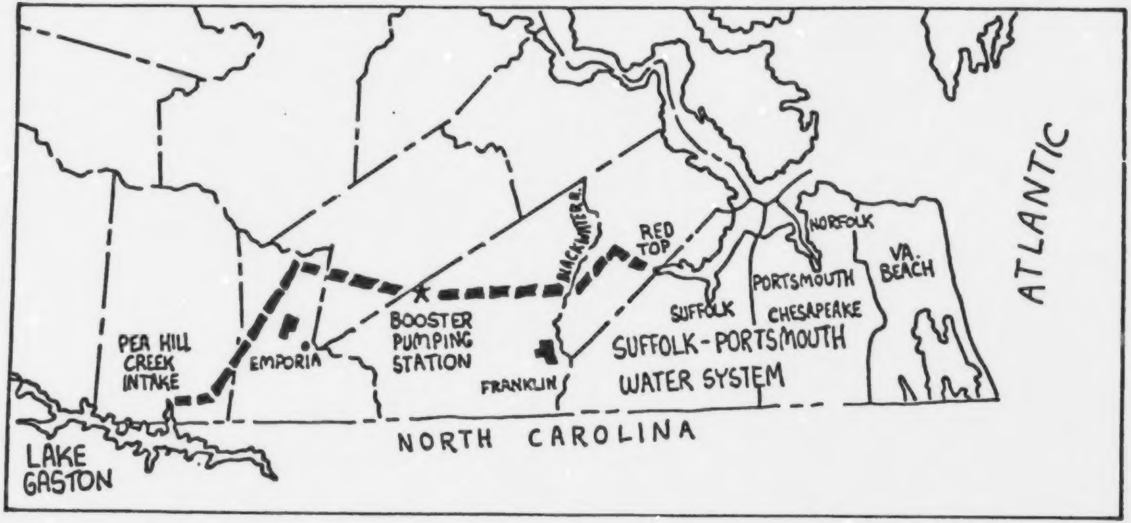
ATLANTIC
VA. BEACH
NORFOLK
PORTSMOUTH
CHESAPEAKE
SUFFOLK
SUFFOLK - PORTSMOUTH
WATER SYSTEM
RED TOP
BLACKWATER R.
FRANKLIN
BOOSTER
PUMPING
STATION
EMPORIA
PEA HILL
CREEK
INTAKE
LAKE
GASTON
NORTH CAROLINA

FIGURE 1

The Lake Gaston option would take water from a reservoir owned by Virginia Power on the Roanoke River. Once withdrawn, the water would be transported through a 60-inch water line approximately 85 miles long to Norfolk's raw-water transmission system in Suffolk.

GEOGRAPHIC ASPECTS OF THE SOLUTION

The Roanoke River originates in the eastern half of the Blue Ridge Mountains and flows southeasterly to Albemarle Sound in North Carolina. Its drainage basin, 9,660 square miles, lies entirely within Virginia and North Carolina; 64 percent of the basin lies in Virginia. The river stretches 80-mile from the headwaters of the Buggs Island Lake in Virginia to the Roanoke Rapids project. Seventy-three percent of the basin above the Roanoke Rapids dam lies in Virginia.

The John H. Kerr Dam, whose reservoir (Buggs Island Lake) is mainly in Virginia, is one of the projects built pursuant to the Flood Control Act of 1944. The principal purpose of the 1944 legislation was to build water projects to capture flood waters and thus to prevent flood damage. Congress took note of additional benefits, including the sale of electric power and storage of surplus water for municipal water use, in determining whether each project would produce enough benefits to offset its costs. The act expressly authorized the sale of electric energy[1] and the sale of surplus water for domestic and industrial uses.[2]

Kerr Dam was completed in 1953, and the reservoir was filled in 1954. At approximately the same time, Virginia Power obtained a license from the Federal Power Commission (FPC)[3] to build the Roanoke Rapids dam site in North Carolina, downstream from Buggs Island Lake, and it was completed in 1955. In 1960, Virginia Power obtained a license from the FPC to construct the Lake Gaston dam between the Roanoke Rapids project and Buggs Island Lake. The dam, completed in 1964, was built 145 miles upstream from the mouth of the Roanoke River.

The Roanoke River below the Roanoke Rapids dam supports the reproduction of an abundant population of anadromous fish--principally striped bass. Minimum river flows are not sufficient during spawning season, and larger discharges are required from Buggs Island Lake.

ACTION BY VIRGINIA AND NORTH CAROLINA

When Virginia Beach initiated its preliminary engineering studies to identify and evaluate its water supply options, Virginia and North Carolina officials generally recognizes common problems withdrawal of groundwater and water quality in Tidewater Virginia and northeastern North Carolina, and that solutions would require interstate cooperation. To facilitate solutions, North Carolina Governor James B. Hunt and Virginia

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[1] Id at Sec. 5, 58 Stat. 890

[2] Id at Sec. 6, 58 Stat. 890

[3] The Federal Power Commission has been renamed the Federal Energy Regulatory Commission (FERC).

Governor John B. Dalton revived a bistate committee in April 1978 that had studied matters of mutual interest from 1974 to 1976. Under a new agreement, the states undertook to develop and establish:

1. Suitable institutional arrangements for interstate and federal cooperation on water resource matters of mutual interest to the two states;
2. Suitable arrangements for sharing the water supply of interstate waters without adverse effects on the citizens of either state;
3. An official joint position on major issues, questions, and proposals on the broad topics of water resources management and water quality control that significantly involve the common or several interests of both states;
4. A joint policy providing that federal or federally licensed water resource developments along or near the boundary between the states shall be planned and operated so as to put the waters to beneficial use to the fullest possible extent.
5. A joint policy to facilitate flood control and watershed protection projects in either state by working to prevent adverse effects from these increased or decreased flows or drainage; and
6. A joint policy on the equitable sharing of water supply storage in federal or federally licensed projects on or near the boundary between the states.

Pursuant to this agreement between the governors, a series of subcommittees with representatives from both states was established to work on the technical issues associated with the various problems.[4] Progress was made, and as late as August 22, 1983, the representatives from Virginia thought they had reached an understanding whereby Virginia agreed to undertake certain actions in exchange for North Carolina's agreeing not to oppose the Virginia Beach pipeline project. At this time, however, the Senate race in North Carolina between Governor Hunt and Senator Jessie Helms began to heat up, and on August 25, 1983, the secretary of natural resources for North Carolina announced at a public hearing on the Virginia Beach pipeline proposal that North Carolina would oppose the project. Cooperation between the two states has ceased.

TIME FOR ACTION

Virginia Beach is faced with the prospect that, under average conditions, it will not have sufficient water to meet its projected demand by 1990, and if a significant drought occurs, the available water supply might be as much as 50 percent of its projected need, even with severe conservation. The city thus decided in 1983 to implement the alternative to secure water from Lake Gaston. To construct its water supply pipeline, which would cross several rivers, and to build appurtenant structures in Lake Gaston, the city filed for a permit with the U.S. Corps of Engineers on July 15, 1983.[5]

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[4] Virginia Beach's water supply; a ground water cone of depression originating in Franklin, Virginia; and water quality problems in the Chowan River and Albemarle Sound were the basic issues examined by the bistate subcommittees.

[5] A permit is required pursuant to Sec. 10 of the Rivers and Harbors Act of 1899 (30 Stat. 1151, 33 U.S.C. 403) and Sec. 404 of the Clean Water Act of 1977 (P.L. 95-217, 33 U.S.C. 1344). The Department of the Army is required to issue a permit for construction in or over navigable waters, as well as for dredging or filling navigable waters, or the accomplishment of any work affecting the course, location, condition, or capacity of such waters.

Virginia Beach also decided to contract with the Corps of Engineers for storage rights in Buggs Island Lake pursuant to the Water Supply Act of 1958,[6] thus ensuring the availability of 60 mgd at Lake Gaston for withdrawal purposes. The storage had to be purchased in Buggs Island Lake rather than Lake Gaston because the operating agreement between the Corps of Engineers and Virginia Power requires that the water level at Lake Gaston remain relatively constant.

The granting of permits by the Corps of Engineers is predicated on compliance with the National Environmental Policy Act (NEPA).[7] It requires that a "detailed statement" be prepared for "major" federal actions significantly affecting the quality of the human environment.[8] This detailed statement since has come to be known as an environmental impact statement (EIS). Corps regulations for to NEPA break down Corps activities into "Actions Normally Requiring an EIS"[9] and "Actions Normally Requiring an Environmental Assessment" (EA) but not necessarily an EIS.[10] Regulatory permits fall into this latter category.

Unless a permit proposal clearly involves an activity with significant environmental impacts, an environmental assessment is first prepared to determine whether or not an EIS is necessary. After the environmental assessment is prepared, the impacts identified must be evaluated to see if they will "significantly" affect the quality of the "human environment."

The following are the ten evaluation factors the Corps considers to determine significance[11] and the determinations the Corps made in evaluating Virginia Beach's water supply application:

1. Adverse environmental impacts
2. Public health and safety
3. Unique characteristics of the geographic area
4. Effects on the quality of the human environment are likely to be highly controversial
5. Possible effects on the human environment are highly uncertain or involve unique or unknown risks
6. The action establishes a precedent for future action
7. The action is related to other actions with individually insignificant but cumulatively significant impacts

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[6] Water Supply Act of 1958, P.L. 85-500, 72 Stat. 319.

[7] National Environmental Policy Act of 1969, P.L. 91-190, 42 U.S.C.A. Secs. 4321-4370.

[8] Id. at Sec. 4332.

[9] 33 C.F.R. 230.6.

[10] 33 C.F.R. 230.7.

[11] 40 C.F.R. 1508.27(b)(1)-(10).

8. The action may adversely affect objects listed or eligible for listing on the National Register of Historic Places
9. The actions may adversely affect an endangered species
10. The action threatens a violation of federal, state, or local law

In addition to its application to the Corps for permission to construct a pipeline over navigable waters, Virginia Beach entered into a contract with the Corps to purchase 10,200 acre-feet of storage in Buggs Island Lake--the amount required to assure 60 mgd even during drought periods--to make the proposed withdrawal from Lake Gaston more secure. Under federal law, this agreement requires a reallocation of storage from hydropower to water supply in Buggs Island Lake. The cost was $2 million, based on replacement cost of the storage for 10,200 acre-feet of water.[12] Virginia Beach will also be required to pay 0.5 percent of the annual operation and maintenance expense, estimated to average about $6,500 per year.

On December 7, 1983, the Corps issued a "Finding of No Significant Impact" (FONSI) on the application by Virginia Beach for permits under Sec. 10 of the Rivers and Harbors Act and Sec. 404 of the Clean Water Act. In essence, the Corps found the Environmental Assessment to be adequate and the need for a complete environmental impact statement to be unnecessary. In response to the FONSI, the governor of North Carolina expressed concern with the Corps' findings on December 29, 1983, and January 4, 1984.

POLITICAL REPERCUSSIONS

The Corps' granting of the permit on January 9, 1984, elicited several responses. In the strictly political response, representatives from southeast Virginia and North Carolina asked that Congress' water resources subcommittee hold a public hearing on the issuance of the permit. They also sponsored a bill that would require the Corps to prepare a full environmental impact statement.

LEGAL ACTIONS IN FEDERAL COURT

On the day the Corps issued the permit to Virginia Beach, the city filed two suits in Federal District Court in Norfolk. The first suit was against the state of North Carolina and the Roanoke River Basin Association, a group that includes eight counties in North Carolina and four counties in Virginia. In its court filings, the association claims to represent 300,000 people and to speak for 1.3 million individuals. The second suit involves riparian landowners below the Roanoke Rapids dam who have an interest under the common law of North Carolina in the stream flow past their property.

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[12] Purchased storage was one-half percent of the total storage's replacement value of $400 million.

The suit against North Carolina and the Roanoke River Basin Association seeks a declaratory judgment that the Corps permits in fact comply with federal law and therefore are valid. This action by Virginia Beach is predicated on the assumption that North Carolina would sue the Corps in Federal District Court in Raleigh and that the suit would not provide a proper vehicle for a complete adjudication of the permit issues against all project opponents. Virginia Beach postulated that even if the permits were upheld in that suit it might later face challenges from other project opponents. The city also determined that it could not afford to have one lawsuit after another, because each petitioner sought to have his cause litigated separately.

Virginia Beach also filed suit against Champion International Corporation and Weyerhaeuser Company, both in their own right as riparians and also as representatives of all other owners of riparian lands on the Roanoke River below the Roanoke Rapids dam. This class of all riparians below Roanoke Rapids dam is so large that the joinder of all members is impractical. The prosecution of separate actions by or against individual members of the class would create a risk of inconsistency and varying adjudication that could establish incompatible standards of conduct for Virginia Beach. The suit seeks a declaratory judgment that the defendants and members of the class have no right to the use of the water that will be diverted from the Roanoke River.

On January 12, 1984, three days after the Corps issued the permit to Virginia Beach, North Carolina brought suit against the Corps in the Federal Court in Raleigh. North Carolina is challenging the Corps' right to issue the Virginia Beach permit without performing a formal EIS. The Roanoke River Basin Association joined with North Carolina in this suit in March 1984. A ruling for a formal EIS at a minimum will delay the project considerably. If it successfully argues for an EIS, North Carolina will get, as one observer has stated, "two more bites at the apple": another suit to contest the adequacy of the EIS and a third suit to challenge the agency's actions in light of the EIS.[13]

LITIGATION STATUS

All of the cases in the two federal courts involving North Carolina, Corps of Engineers, Virginia Beach, and Roanoke River Basin Association have been consolidated into one case in the U.S. District Court in Raleigh. On July 7, 1987, the court rendered its decision. It directed the Corps to make an independent assessment of the effects of the proposed project on striped bass to determine whether the preparation of an EIS is required or whether any mitigative measures are necessary and, as part of its public interest review, make a determination of the extent of Virginia Beach's water needs. The court retains jurisdiction of the case for further review and directs the Corps to file with the court the results of its reconsideration and the record supporting its decision.

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[13] Heath, supra note 19.

CONCLUSIONS

The experience of Virginia Beach in seeking an additional source of water that involved a transbasin diversion suggests some obvious conclusions. It also serves to emphasize the importance of political and institutional issues that must be addressed and they may be more important than the technical and economic considerations.

1. There must be a more rational way of managing the public water resources of a state or province to balance the concerns of both the exporting and importing areas for the benefit of all.

2. The courts, as a water management institution, are very expensive and exceedingly slow.

3. Water allocation will always be an emotional issue because everyone has a potential interest in it; therefore, any transbasin diversion, especially one crossing political boundaries, must be approached with much more care for the political issues rather than the technical and economic aspects of the transfer.

4. Water supply traditionally has been a local responsibility and is likely to remain so in the United States. Many localities in the future will face water demands they cannot resolve internally from existing water sources. The state will have to assume a larger responsibility to create an institutional structure that will allow local governments to deal with their water problem efficiently and effectively. Local governments will strain to provide the capital resources needed to address their water needs. Very few can afford a four- or five-year court battle, as Virginia Beach endured or some other administrative activity as a prologue to a construction project.

5. States will have to provide more leadership than they have in the past because local governments cannot deal with the externalities associated with a transient resource such as water.

THE INSTITUTIONAL CREATION OF WATER SHORTAGES ON THE CANADIAN PLAINS

DAVID R. PERCY*

ABSTRACT

The allocation of water rights on the prairies has resulted in licensees holding very secure water rights, which can be transferred only in rare circumstances and cancelled on limited grounds. These features of water rights law combine to make water shortages inevitable. A concern with the deficiencies of prairie water law has led in recent years to a number of reforms, which are characterized by grants of broad discretion to administrators to resolve problems on an ad hoc, case by case basis. These types of reform fall into two broad categories: the housekeeping approach, exemplified in Alberta and Manitoba and the apparently radical changes which were enacted in 1984 in Saskatchewan. However, the writer concludes none of the reforms cure the glaring defects of prairie water law. He outlines some alternative suggestions which would both address the present defects and, by increasing the transferability of water rights, would reduce the risk of water shortages on the prairies.

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A. INTRODUCTION

The possibility of inter-basin transfers is in the air again on the Canadian prairies. The diversion of water from the abundant supplies of the northern portion of the region to the parched south is raised from time to time, especially in Alberta.[1] In the seventies, Manitoba carried out, for the purpose of generating hydro-electricity, the major Churchill River Diversion, which has been the focus of much attention at this Symposium.[2] In the recent past, the Garrison Project created the possibility of an inter-basin transfer with major international implications.[3]

As the range of papers presented at the Symposium show, major inter-basin transfers create large environmental, technical, economic and even meteorological issues. In the face of these crucial questions, it is legitimate to investigate the role that can be played by a legal analysis of the problem. At the least, inter-basin transfers have three important legal dimensions:

(i) A major inter-basin transfer is almost certain to interfere with vested rights in the region of origin and to create legal problems in the region whose water supply is to be augmented. As a result, the legal implications of any project must be understood in advance and the transfer must be preceded by careful legal groundwork, especially in respect of its effect on existing rights. These questions are more of a technical nature and were briefly canvassed by the author at a Conference on Inter-basin Transfers in 1980.[4]

(ii) Most major transfers will affect inter-provincial waters. This raises issues of both constitutional law and conflict of laws, which were briefly explored at the 1980 Conference and which were addressed by Owen Saunders at this Symposium.[5]

(iii) Most important proposals for inter-basin transfers are inspired by actual or threatened water shortages in the region that would be benefitted by the transfer. It is widely accepted that the question of whether a water shortage exists is economic rather than physical in nature, but the question also has an important legal aspect, which is frequently overlooked. The nature of the legal rights held by existing users can clearly influence the availability of water. This proposition is starkly illustrated by prairie water law, which limits the supply of water that can be obtained by new users to an extent that makes demands for inter-basin transfers inevitable.

All three legal dimensions of inter-basin transfer proposals are important. It is the purpose of this paper to deal only with the third, by examining the effect of the law of water allocation on the demand for water on the prairies. This examination involves an investigation of firstly, the allocation of water rights in the prairie provinces, secondly the effect of recent reforms in the law of water rights and thirdly some alternative strategies for dealing with the glaring defects of the present law.

B. THE PATTERN OF WATER RIGHTS IN THE PRAIRIES

The water law of the prairie provinces shares a common historical root, which is explained by constitutional history. In 1894, the Federal Government passed the North-West Irrigation Act[6], which applied a uniform law of water allocation in most of the area that now comprises the prairie provinces, with the exception of a small part of southern Manitoba, which was then a province in its own right. When Alberta and Saskatchewan were carved out of the North West Territories in 1905, the Dominion retained both the ownership of and legislative control over water resources, as it did in those regions that were added to Manitoba by the Manitoba Boundaries Extension Act of 1912.[7]

In 1930, the Federal Government transferred to the respective prairie provinces the resources that had previously been vested in it[8] and, as a result, each province obtained the right to pass its own water legislation. However, rather than investing enormous resources in drafting new Acts, Alberta, Saskatchewan and Manitoba each simply adopted the former federal Irrigation Act as provincial legislation, with only minor amendments of a technical nature.[9] Although divergences from this basic model of water law naturally occurred over the years, it was not subjected to any fundamental re-examination until the Saskatchewan Water Corporation Act was passed in 1984.[10] Most water rights on the prairies were thus granted under the basic legal model and it remains influential today, even in Saskatchewan.[11]

1. The Initial Allocation of Water Rights

The technique of granting water rights on the prairies is based upon a legislative declaration which ensured that the Crown owned all the water in each province.[12] The Crown then established a mechanism to distribute its ownership rights by means of licences, which were granted for specific quantities of water to applicants on a first come, first served basis. As a result of this process, a typical licensee would receive the right to divert a quantity of water, perhaps subject to seasonal restrictions. Early licences were routinely issued for an unlimited term and, particularly in the case of irrigation districts, frequently entitled the holder to large volumes of water. Thus, for example, the Alberta licence of the Eastern Irrigation District entitles the district to divert 562,000 acre feet of water, apparently in perpetuity.[13]

Once a licence is issued, the water user enjoys an unusual degree of security. The quantity of water to which the licensee is entitled can be reduced in times of shortage by the application of the principle of prior allocation, under which water is distributed according to the seniority of the licence holder.[14] Thus, if there is insufficient water in a particular basin to supply all licensees, the earliest licensee is entitled to receive the entire quantity of water stipulated in the licence before the next licensee can receive any water at all. The second licensee has similar rights against subsequent licensees and the entire scheme can be enforced, if necessary, by closing the source of supply of licensees in reverse order of seniority.[15] Although this has long been the only general method of allocating water in times of shortage which is legally authorized, the results of its application are rarely seen in practice. Water administrators have preferred to negotiate a sharing of supplies among users rather than to impose the strict scheme of the legislation.[17]

Exceptions to the principle of prior allocation can be made if the Lieutenant-Governor in Council reserves unallocated water from the ordinary licensing system. Once water has been reserved, it can be allotted at the discretion of the Lieutenant-Governor, who may stipulate an order of precedence for among users of reserved water, which differs from the principle of prior allocation.[16] In addition, it is arguable that owners of riparian land retain certain minor rights, which are also exempt from the ordinary priorities under the legislation.[17]

Except in the rare event that a licensee's entitlement is reduced by the application of the prior allocation doctrine, water rights granted by licence are virtually permanent. In Alberta and Manitoba, a licence can be cancelled only if a licensee commits one of a series of misdeeds stipulated in the legislation, such as wasting water or breaching a provision of a licence, the Act or the Regulations.[18] Manitoba allows a licence to be cancelled if the licensee abandons any water to which he or she is entitled.[19] Saskatchewan's former Water Rights Act contained similar powers of cancellation, but they were supplemented by a broad right of expropriation, which has been carried forward in the new provincial legislation. In Saskatchewan, a licence granted under the former Water Rights Act can be cancelled, with the approval of the Lieutenant-Governor, if it is considered to be in the public interest to do so, with only a limited right of compensation for the actual value at the time of cancellation of any works that were used to secure and transport water to the point of use.[20]

2. The Basic Model and Water Shortages

The system of distributing water rights on the Canadian Plains was designed to encourage development by making water available at no cost to agricultural settlers. Although this was not a concern in 1894, it created the obvious danger that water supplies would soon be totally committed to licensees, leaving no water available for new users. The danger was realized as early as 1919 and it inspired the enactment of the reservation power, which was used to prevent certain bodies of water from being allocated under the licensing system.[21] However, the reservation power in practice could only be exercised where water at a particular location had a clear potential use, frequently for the generation of hydro-electricity, which would be denied if the flow was licensed to others. In the ordinary scheme, water rights for an indefinite term were granted to licensees subject only to the principle of prior allocation and to the limited powers of cancellation and modification described in the previous section.

The problems caused by the virtually irrevocable commitment of water supplies to early users are exacerbated by the absence of any effective mechanism to permit even the voluntary transfer of water rights from existing licensees. The original federal legislation made no provision to permit the transfer of water rights, unless the new user acquired the land of an existing licensee and continued to use the water for the same purpose.[22] The disastrous potential of this restriction became evident when, shortly after the First World War, the fear arose that the large scale allocation of water rights to irrigation in southern Alberta might prevent growing towns from securing an adequate water supply. In response, the government amended the Irrigation Act in order to implement a very limited system for the transfer of water rights. The legislation created a statutory table of preferences, which gave the highest priority to the use of water for domestic purposes, followed in order by uses for municipal, industrial, irrigation and other purposes.[23] The only practical importance of this table is that to permit a person who requires water for a highly ranked purpose to obtain, by expropriation if necessary, a licence that was granted for an inferior purpose. Thus, for example, a municipality can acquire water that is used for industrial or irrigation purposes, but not vice versa.

The table of preferential uses changed only in matters of detail in Manitoba and Alberta and under the former Saskatchewan statute.[24] The restricted transfer system is clearly no solution to the rigid patterns of water use created by prairie legislation, for it is based on a list of statutory priorities that is the result of historical accident rather a conscious effort to specify the relative importance of different types of water use. Even if the table of priorities did reflect social preferences when it was enacted or amended, it would almost certainly be outdated today. In addition, it is founded on the false premise that it is possible to state that some uses of water are more important than others at all times and in all regions of a province. The importance of this objection is emphasized by the statutory prohibition against even desirable transfers of water rights that conflict with the priorities established by the table.[25]

The basic model of prairie water law guarantees that there will be water shortages on the Canadian plains, for once water has reached the point of full allocation, as it has throughout the dry belt, there is no realistic method of providing water to new users. Only limited transfers are authorized under the table of preferential uses and they occur rarely, if ever, in practice. Although it is possible to obtain a water right by acquiring the land of an existing licensee, administrative approval is still required if the transfer involves a change of use. In any event, this mode of acquisition may force the new user to become established in an undesirable location and to bear the unnecessary costs of acquiring land.

In effect, an intending water user will frequently either be unable to obtain a right or will receive a right which is insecure, because it holds a low priority. When water rights are no longer available, because the basin is fully allocated, it is inevitable that a clamour will arise to increase the natural supply of water, initially by the construction of storage facilities and ultimately by instituting inter-basin transfers. The law, by either preventing or imposing unnecessarily high costs on the acquisition of water rights, prevents water from being made available from existing users and ultimately creates the conditions in which an inter-basin transfer seems to be the only solution to the problem.

The rigidity of the basic model of water allocation law alone should be the cause of great concern. A closer economic assessment reveals that it contributes to water shortages in less obvious ways. The secure water rights enjoyed by existing licensees are usually granted either free or for a purely nominal charge. Any reduction in consumption thus does not provide a saving in cost to the licensee. Indeed there is a total absence of incentive for existing users to make water available for newcomers. Most conservation measures, such as, for example, the installation of modern irrigation equipment, will impose extra costs which cannot be recouped, because the licensee is prohibited from disposing of surplus water to newcomers. In effect, the failure of the basic model to take into account the marginal value of water tends to encourage licensees to consume as much water as possible in their operations, if they can thereby minimize the cost of other inputs for which they are required to pay a price.[26]

Perhaps because the defects in the basic model have begun to emerge, a number of changes have been made in prairie water law in recent years. The most significant changes will be examined in the following section.

C. PATTERNS OF CHANGE

The responses of each of the prairie provinces to the necessity of adapting to the demands of the late twentieth century a system of water allocation that was born in the nineteenth century fall into three broad categories. The measures adopted have included the administrative adaptation of the present law, minor legislative amendments and sweeping statutory changes. Each type of response will be surveyed in turn.

1. Administrative Adaptation

There has been a discernible trend in water administration to leave the resolution of difficult problems to the discretion of officials rather than to attempt to formulate and apply detailed statutory rules. This trend has been particularly evident in Alberta, where the exercise of discretion is the hallmark of the administration of water rights. Discretion is even employed to avoid the terms of the Water Resources Act on occasion, when their application might give rise to unacceptable results. The technique is evidenced by the practice, described earlier,[27] of officials who prefer to negotiate proportionate reductions in water use during times of shortage then to insist upon the harsh principle of prior allocation.

In modern licences in Alberta, attempts are routinely made to avoid the rigidities of the basic model of water law through the insertion of terms and conditions into licences. The long-term commitment of water to a particular user is often avoided by a term which states that the rights and privileges granted under the licence "are subject to periodic review in the public interest and more particularly to ensure the preservation of the rights of other water users."[28] For the same reason, water licences are now sometimes issued for a fixed term,[29] so that the water can revert to the Crown for re-allocation at the end of the term.

This approach suggests that the Alberta Department of Environment is dissatisfied with some areas of the Water Resources Act, but that it chooses to circumvent those areas through the exercise of departmental discretion rather than to enact fundamental revisions. In many cases the results of this process is uncontroversial and beneficial, but it also creates a number of risks. Under ordinary principles of administrative law, any ter and conditions inserted into a licence must not contradict t parent Act. Even if there is no conflict, the terms a conditions must be consistent with the underlying policy of t Act. On these criteria, the provision for the periodic review a licensee's rights, described in the previous paragraph, obviously suspect, as it departs from the principle of pri allocation enshrined in the legislation. As this examp illustrates, there are strict limits to the extent to which t Water Resources Act can be adapted to modern conditions administrative means.[30]

2. Minor Legislative Amendments

Two provinces have attempted to modernize the bas model by legislative amendments. In Alberta, the Water Resourc Act has been frequently amended in a piecemeal fashion, a specific problems have emerged. From time to time, th legislation is rearranged and updated.[31] In 1983, Manitoba, whos legislation most closely resembled the last federal Irrigatio Act, thoroughly revised its Water Rights Act, although the change were not finally implemented until 1986.[32] The new Manitob legislation makes some significant changes in the law of wate rights. It alters the list of priorities in water use and grant a power to cancel a water licence "where in the opinion of th Minister, it is in the public interest to do so."[33] It als increases penalties for breaches of the legislation and allows right of appeal to the Municipal Board by any person who i affected by an order or decision of the Minister under the Act.[3 In addition, the Act was thoroughly modernized through th omission of redundant provisions and of much archaic language.

Despite the changes in form and substance to the Albert and Manitoba statutes, their underlying philosophy remains unchanged. The approach to reform in these two provinces may well reflect an appreciation that the basic model of water rights has many virtues and that it has successfully fulfilled its original expansionist. However, it is clear that the housekeeping approach to reform in Alberta and Manitoba has not addressed the serious defects that were outlined in the previous section of this paper.

3. Sweeping Statutory Change: The Saskatchewan Water Corporation

In contrast to the tinkering with the basic model that has occurred in Alberta and Manitoba, Saskatchewan enacted apparently fundamental reforms in 1984.[35] Under the new legislation the law of water rights, which extended to 68 statutory sections in its last consolidation in 1978, was compressed into 7 sections and placed under the administration of the Saskatchewan Water Corporation.

The effect of the new Act on water rights will be assessed by considering firstly its application to water rights that came into existence after its proclamation in 1984, and secondly its application to water rights granted by licence under the former legislation.

(i) Rights Granted by the Corporation

The method of granting water rights under the new legislation has undergone substantial change. Rights are now allocated by the Water Corporation rather than the Crown, so that the Corporation is empowered to grant the right to use water to any person, unless the water has already been allocated to someone else or has been withdrawn from allocation by the Minister.[36]

The remarkable feature of this aspect of the legislation is that it provides no guidance relating to the allocation of rights or to the inter-relationship of water rights once they have been issued. Almost all major issues are left to the unfettered discretion of the Corporation, including the sharing of water during times of shortage. The Act no longer enshrines the principle of prior allocation, but water rights disputes can still arise, and they are likely to be referred to the Corporation for resolution.[37] However, there is no statutory indication as to the principles that the Corporation must apply in deciding the entitlement of various users to the available water.

The new legislation makes even less provision than its predecessor for the transfer of water rights to new uses, because the limited provisions permitting the transfer of water rights have been abolished and the sweeping expropriation power does not apply to water rights created after 1984. New water rights can be cancelled without the consent of the holder if the right was granted for a temporary period which has expired, if the holder fails to comply with any conditions imposed in the grant, or if the water is no longer used for the purpose for which it was acquired.[38] The Corporation can also cancel a water right if it considers that the holder no longer requires the right or a portion of it,[39] but there must be some basis for exercise of this power and it would be difficult to sustain if the holder of a water right was still using water. As a result, the restricted powers of cancellation mean that the pattern of water rights granted after 1984 in Saskatchewan is more rigid than it was under the former legislation.

(ii) Rights Granted Under the Water Rights Act

The central principle of the new Act is that water rights granted by licence prior to 1984 are expressly preserved, unless and until they are amended or cancelled by the Corporation.40 This clause apparently guarantees the security of pre-1984 rights unless they are expropriated, for the Corporatio has no other means of amending of cancelling them. However, th manner in which pre-1984 rights are preserved leaves open a argument that some of the old grounds of cancellation still apply

The Act preserves the rights of licensees as the existed "on the day on which" the Water Corporation Act came int force.[41] It will be recalled that licensees under the forme legislation did not have an absolute right to the quantity o water stipulated in the licences, because the right could b cancelled if the licensee committed certain delinquencies and i could be limited by the application of the principle of prio allocation. Because the legislation does not increase the right of licensees under the former Act, it can be argued that they ar subject to all the limitations that were found under the Wate Rights Act. However, it must be noted that this interpretation o the new Act is not self-evident and is not shared by al commentators.[42]

If there is insufficient supply to provide water to the holder of a right granted before 1984 and to the holder of a new right, the Act appears to grant preferential treatment to the older right. Because the right of a pre-1984 user is in full force and effect unless it is amended or cancelled by the Corporation, the Corporation cannot by implication reduce that right by the grant of new water rights.

(iii) An Evaluation

In some ways, the Water Corporation Act exemplifies the current tendency[43] to leave many water rights decisions to the discretion of officials. The Act fails to deal with virtually every important question in the administration of water rights and thus by default leaves those issues to be decided at the discretion of administrators at the Water Corporation. It thus creates a potential for arbitrariness that is unprecedented in modern water law in North America.[44]

Despite the radical nature of the new Saskatchewan legislation, it fails to address the serious problems of prairie water law that were identified earlier.[45] It makes no provision for releasing water held by existing rights holders to new users, for curing rigidities in the allocation of water rights or for encouraging efficiency in water use. Although the enactment of the legislation was part of a large reorganization in water administration, it can only be concluded that it has had a detrimental effect on the law of water rights.

D. REFORM SUGGESTIONS

Both the small-scale reforms in water rights law in Alberta and Manitoba and the more fundamental reforms in Saskatchewan do not seem to be based upon a clear appreciation of the defects of the present law. It was argued earlier that the present law virtually guarantees that there will be water shortages on the Canadian plains and that, as a result, there will be calls for the augmentation of supply through inter-basin transfers. This defect could be cured by the enactment of relatively simply reforms, with a resulting decrease in the demand for transfers.

The overall problem in the basic model of western water law is that it was developed in the nineteenth century in order to ensure that secure water rights were granted to those who could put them to economic use. Accordingly, it fails to address the modern problem of allocating water among a large number of existing and potential users in the most beneficial manner. As an initial step, the present restrictions on the transfer of water rights could be removed, thus allowing licensees to transfer all or part of their entitlement to any new users. Subject to the supervision of the controller of water rights or some similar government officer, licensees could be empowered to dispose of water rights in the same manner as owners of other valuable resources, such as urban land or interest in oil and gas, unless there is some compelling objection to the disposition.[46]

Such a modest reform could well release water which is presently used at low levels of efficiency to more productive uses. At the least, the removal of obstacles to the efficient use of water would permit a rational assessment to be made of the severity of the existing water shortages on the prairies and for the first time allow the need for major inter-basin transfers to be properly measured.

FOOTNOTES

1. For Alberta's best known proposal, see the P.R.I.M. programme, Alberta Department of Agriculture, 1969; see al *Water Supply for the Saskatchewan-Nelson Basin*, Report of th Saskatchewan-Nelson Board (1972), especially at pp. 173-184.

2. See, e.g., Hecky, *Ecological Overview of the Churchill Rive Diversion*; Williamson and Duncan, *Water Chemistry Change Associated with Stream Diversion for Hydroelectri Development in Northern Manitoba*.

3. See, e.g. the discussion of Goldberg, *The Garrison Diversio Project* (1981), 11 Man. L.J. 177.

4. Percy, *Legal and Jurisdictional Aspects of Inter-basi Transfers* (1981), 6 C.W.R.A. Jl.1.

5. *Id.* See also Saunders, *Management and Diversion o Interjurisdictional Rivers in Canada: A Legal Perspective*

6. 57-58 Vic., c.30.

7. See LaForest, *Natural Resources and Public Property under the Canadian Constitution* (1969), p. 34-35 and S.C. 1912, c.32, s.6.

8. The text of the Natural Resources Transfer Agreements can be found in the British North America Act, 1930, 21 Geo. V. c.26 (Imp.), Schedule 2, s.1.

9. See The Water Resources Act, S.A. 1931, c.71; The Water Rights Act, S.M. 1930, c.47; The Water Rights Act, S.S. 1931, c.17.

10. The Water Corporation Act, S.S., 1983-4 c.W-41, s.42.

11. See text, *infra*, p. 12-13.

12. The present formula was first found in 58-59 Vic., c.33, s.2. The modern provisions are now found in The Water Resources Act, R.S.A. 1980, c.W-5, s.2(1) (Alta.); The Water Rights Act, R.S.S. 1978, c.W-8, s.7(1) (Sask.); The Water Rights Act, C.C.S.M., c.W-80, s.7(1) (Man.). In the remainder of this paper, this legislation will be cited by reference to the name of the province only. All references to Saskatchewan legislation refer to The Water Rights Act, unless otherwise noted.

13. Licences No. 111A, 19A on the Bow River Drainage Basin, January 4, 1963, purporting to incorporate the terms of a Permit dated February 25, 1915.

14. Alta., s.35(1); Sask., s.40(1); Man., s.12(2).

15. Alta., s.35(1); Sask, s.40(1); Man. s.12(2).

16. Alta., s.12(1); Sask., s.15(8); Man., s.12(8).

17. See Percy, The Framework of Water Rights Legislation in Canada. At the time of writing, this publication is in press at the Canadian Institute of Resources Law. The problem of riparian rights is discussed at pp. 15-20 of the original manuscript.

18. Alta., s.50, s.52; Man., s.38, s.27.

19. Man. s.38.

20. See now The Water Corporation Act, S.S., 1983-4, c.W-41, s.42.

21. Percy, Water Rights in Alberta (1977), 15 Alta. L. Rev. 142, 152-153.

22. Percy, op. cit. supra, footnote 17, p. 22.

23. An Act to Amend the Irrigation Act, S.C. 1920 c.55 s.4.

24. In Alberta, the relative positions of irrigation and industrial uses are reversed and water power is ranked as 5th priority, ahead of other uses; see Alta., s.11. In Saskatchewan, mineral water and mineral recovery purposes were ranked as 6th and 7th on the list, after other purposes; see Sask., s.15(3). In the new Manitoba Water Rights Act, S.M. 1982-83, c.25, s.9, agricultural uses were added to the table, following municipal uses and ahead of industrial uses. See also text, infra, page 10.

25. See Percy, Water Rights Law and Water Shortages in Western Canada (1986), 11 Canadian Water Res. Jl. 14, 19.

26. On this point, see Gysi, Measuring the Need for Inter-basin Transfers, a paper delivered at a Conference on Inter-basin Transfers, University of Alberta, Edmonton, Alberta, August 27 and 28, 1980.

27. See text, supra, p. 4.

28. See, e.g., Alberta Licence Number 2158, December 20, 1985, issued to the Provincial Crown and the Wagner Natural Area Society.

29. See, e.g., Interim Licence Number 12298, June 15, 1983, which was issued to a major water user for a ten year term.

30. This point was emphasized by the Alberta Court of Queen's Bench decision quashing all the licences and permits issued for the Oldman River Dam. See *Friends of the Oldman River Society* v. *Minister of the Environment*, Alta. Q.B. Action No. 8701-15578, Reasons for Judgment, December 8, 1987.

31. See, e.g., The Water Resources Amendment Act, S.A. 1981, c.40.

32. The Water Rights Act, S.M. 1982-83, c.25, s.9, proclaimed December 1, 1986; see (1987), 116 The Manitoba Gazette, p. 25.

33. *Id.*, s.9, s.19(1).

34. *Id.*, s.23, s.24.

35. The Water Corporation Act, S.S. 1983-84, c.W-41, s.42.

36. *Id.*, s.41(3).

37. *Id.*, s.65; for a discussion of the options available to the Corporation, see Percy, *op. cit. supra*, footnote 17, p. 36-37.

38. *Id.*, s.41(5).

39. *Id.*, s.41(5)(d).

40. *Id.*, s.80(1).

41. *Ibid.*

42. See Barton, *The Saskatchewan Water Corporation* [1984] Resources, No. 9.

43. See text, *supra*, pages 8-9.

44. See further the discussion in Percy, *op. cit supra*, footnote 25, at p. 19-20.

45. See text, *supra*, pages 5-8.

46. For a more detailed discussion of the implementation of transfers under the basic model, see Percy, *op. cit. supra*, footnote 25, pp. 20-21.

MANAGEMENT AND DIVERSION OF INTERJURISDICTIONAL RIVERS IN CANADA: A LEGAL PERSPECTIVE

OWEN SAUNDERS*

ABSTRACT

While it is often the case that the rational unit for management of river systems is the watershed, this rarely conforms to political boundaries. How Canadian governments have accommodated the legal realities of fragmented jurisdiction to the physical realities of river systems is the subject of this paper.

The paper begins with a description of the constitutional setting for river management in Canada. While the provinces and the federal level both clearly possess some regulatory authority, there are significant jurisdictional ambiguities which have yet to be explored by the courts. Perhaps even greater doubt attaches to the respective rights of provincial governments *inter se* in manipulating a shared river.

Canadian governments have generally performed well in responding to this legal fragmentation, through a series of interjurisdictional agreements and understandings. These agreements do, however, raise special legal problems, particularly with respect to enforceability. More seriously, the particular framework of Canadian federalism makes the imposition of such agreements extremely difficult where one party remains recalcitrant, even though principles of sound water management might dictate that some co-operation is essential.

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INTRODUCTION

The legal element in interjurisdictional water management has never been as prominent in Canada as in the United States. Where Americans look to the courts for solutions, Canadians prefer the safer course of negotiation. As a result the Canadian jurisprudence on the appropriate roles for different levels of government with respect to managing shared water resources is extremely thin. While most water diversions in Canada are admittedly largely intra-provincial in their direct effects, even those that have involved interprovincial or federal-provincial disputes have generally avoided litigation.

For reasons that will be discussed in this paper, however, it is arguable that the legal element in water management will take on an increased importance, at least with respect to shared basins. This paper summarizes the legal bases for federal and provincial intervention in water management as a matter of constitutional law. It then examines how governments have accommodated the needs of water management to the legal rigidities of the *Constitution*; the primary legal technique in this regard has been the intergovernmental agreement. The legal nature of such agreements is then addressed, as well as the legal situation confronting governments when agreements cannot be negotiated.

CONSTITUTIONAL CONTEXT

The constitutional context for water management in Canada has generated a substantial and readily available literature.[1] While authors vary on their evaluation of the strength of provincial and federal powers in this area -- perhaps not surprisingly, given the paucity and ambiguity of judicial decisions to date -- at least there is general agreement on what the important legal issues are. The discussion below is presented in terms of water management in the provinces. In Yukon and the Northwest Territories, of course, the federal government exercises plenary jurisdiction, in effect taking on the full powers that would normally be divided between the provincial and federal levels. While there are interesting questions as to how water management should be shared administratively in the north between territorial and federal agencies, these do not raise any fundamental constitutional questions. It is clear that as a matter of constitutional law any territorial role in water management depends ultimately on, and exists at the sufferance of, the federal authority.

Provincial Jurisdiction

A government in Canada has two major constitutional bases upon which to rest a claim of jurisdiction over management of water resources (and natural resources generally). Firstly, it may be given a role as legislator under the *Constitution Act*; secondly, it may have certain proprietary rights as owner of the resource. Of these two possibilities, provincial governments derive their major powers with respect to water management from the second branch, proprietary rights. The *Constitution Act, 1867* gives "[a]ll Lands, Mines, Minerals and Royalties belonging to the several Provinces ... at the Union ... to the several Provinces ... in which the same are situate."[2] It is now established that this conferring of land ownership carries with it ownership of water rights.

While the main root of provincial authority with respect to water rests in these proprietary rights, provinces are also given a number of legislative powers in the *Constitution Act* which are relevant for water resource management. These legislative powers include section 92(5) (management and sale of a province's public lands), section 92(13) (property and civil rights in the province), section 92(16) (matters of a local or private nature), and section 95 (agriculture, which is subject to a concurrent and paramount jurisdiction in the federal government). These rights have arguably been strengthened by the 1982 Resources Amendment[3] to the *Constitution* -- section 92A -- which, *inter alia*, holds some implications with respect to the use of water in the generation of hydroelectricity. Specifically, section 92A(1) provides that:

> (1) In each province, the legislative may exclusively make laws in relation to
>
> ...
>
> (c) development, conservation and management of sites and facilities in the province for the generation and production of electrical energy.

Additionally, provinces are given the power to legislate with respect to interprovincial exports of their electricity on a non-discriminatory basis (section 92A(3)), and also have expanded capacity to tax such production, again so long as the taxation does not discriminate between production used in the province and that exported to other provinces.[4] My own feeling about section 92A, however, is that it is likely to have only a very limited effect on water resources; its effect should be more pronounced with respect to those resources in which provinces do not exercise proprietary rights (for example, freehold oil and gas).

Federal Jurisdiction

While the provinces rely primarily on their proprietary rights in exercising authority over water management, the federal government draws its mandate largely from certain legislative powers accorded it under the *Constitution Act*. This is not to suggest that the federal government is without proprietary rights. In the northern territories, for example, the federal government exercises full proprietary and legislative powers with respect to water, and even within the provinces may also exercise certain proprietary rights on federal lands -- in national parks for example.

The more interesting question, however, is the extent of federal authority which may exist quite apart from any proprietary interest. In this respect, although the federal government is not given a legislative mandate with respect to water *per se* in the *Constitution Act*, its legislative powers under a number of headings clearly give it a substantial basis for exercising authority over water management concerns. Most obviously the federal fisheries power (section 91(12)) holds significant implications for regulation of water quality -- and even water quantity[5] insofar as it is related to effects on fisheries. The *Fisheries Act*[6] was indeed one of the earliest pieces of Canadian legislation which dealt with environmental concerns -- specifically the protection of fish and fish habitat. However, the fisheries power in itself does not provide the basis for general regulation of water management -- or even water quality. The Supreme Court of Canada has struck down attempts to extend the power beyond certain limits, and has held that federal legislation affecting water management which is predicated on the fisheries power must in fact have some nexus with fisheries. A general prohibition on certain uses of water frequented by fish will not be upheld, for example, if there is "no attempt to link the proscribed conduct to actual or potential harm to fisheries."[7] As one commentator has summed up the courts' view of the fisheries power:[8]

> The guiding principle is clear. Federal fisheries legislation must be demonstrably related to protection or conservation of fishery resources .... It must be concluded that there is little room for indirect federal regulation of provincial resource development through the vehicle of the fisheries power.

Similarly, the federal government has been given legislative responsibility for navigation and shipping under the *Constitution* (section 91(10)), but while this power has been read to extend beyond navigation in the narrow sense to include, for example, licensing of dams and bridges,[9] such actions must nevertheless have some nexus with navigation, and certainly the power has not been given the scope accorded it in the United States.[10] Moreover, if only because of the absence of a relationship to water quality, the navigation power is not up to the task of acting as a general basis for federal authority over water management.

Yet another head of jurisdiction that has been used by the federal government to assume a role in water management for specific purposes is its concurrent jurisdiction with the provinces in agriculture under section 95 of the *Constitution*. This has been most evident in Western Canada, as reflected in the extensive activities of the Prairie Farm Rehabilitation Administration. Again, though, it is impossible to conceive of section 95 as providing a general federal power with respect to water resource management.

If these specific federal powers are inappropriate to construct a more general federal mandate for water management, can we find a broader federal power that fulfills this function? The most obvious candidate is this regard is the so-called general power with respect to peace, order and good government (POGG) in the preamble to section 91. It seems clear, however, that while POGG may support certain interventions by the federal government on specific issues, it would not justify wholesale intervention by the federal level in water management issues otherwise reserved to the provinces. Similar conclusions apply to any such use of the federal trade and commerce power (s.91(2)).

In any event, the interesting question is not whether the federal or provincial level can assert plenary jurisdiction; with the exception of the territories the responsibility for water management under the *Constitution* is clearly a shared one. The real question is how the jurisdiction will be shared between the two levels of government for particular issues. This question is partly answered by examining some of the powers discussed above. However, on some crucial issues the *Constiution* is ambiguous. The ambiguity of most interest in this paper is the role of the respective levels of government in managing shared water resources. Does the federal or provincial role change to some extent when water crosses an international or interprovincial boundary? This question is of course key in assessing the ability of each level of government to exercise authority over water diversions, or at least those diversions which involve shared watersheds.

The easiest case is with respect to waters which cross or form part of an international boundary. Under the Boundary Waters Treaty of 1909[11] the federal government is committed to a number of obligations towards the United States in respect of boundary and transboundary waters. Because of an oddity in the Canadian *Constitution* the federal government is empowered to implement the provisions of the treaty, regardless of whether it infringes on the normal legislative or proprietary rights of the provinces.[12] It is hard to imagine any international diversion that would not come under federal regulatory authority pursuant to the provisions of the treaty.

The federal government has also enacted legislation, going beyond what is covered in the treaty, to require -- under the *International River Improvements Act* of 1955[13] -- a federal licence to interfere with the flow of an international river; river in this legislation is defined very broadly, and would include, for example, a transboundary water pipeline.[14] The constitutional basis for the Act is not absolutely clear. However, there would be a strong argument that it could be justified on the basis of the POGG power, discussed above, and specifically under a branch of the doctrine which gives the federal government jurisdiction over matters of national concern.[15]

The more difficult question concerns those diversions which are interprovincial in scope. It may of course be that the federal government can exercise some power over such diversions by reason of a specified head of power in the *Constitution Act* -- as with fisheries or navigation. Indeed the federal level might be able to intervene in even a wholly intra-provincial diversion using such powers. The more important issue is whether the federal government may exercise some additional jurisdiction in the case of interprovincial rivers; that is, whether the very fact that a river crosses provincial boundaries in some way expands the constitutional mandate of the federal government. Conversely are the powers of a province to deal with its waters in some way restricted by the fact that it is affecting an interprovincial watercourse?

Unfortunately, the exact nature of the federal role in the management of interprovincial waters has not been addressed clearly by the courts. The leading case in the area -- the *Interprovincial Co-operatives* case[16] -- is less than a model of judicial clarity. *Interprovincial Co-operatives* involved a legislative scheme by the Government of Manitoba to compensate fishermen in the province whose livelihood had been impaired as the result of pollution from chlor-alkali plants in Ontario and Saskatchewan. As a result, Manitoba, which was the statutory assignee of the rights held by the fishermen, brought an action against the plant operators. The Supreme Court of Canada ultimately held that the relevant statutory provisions were *ultra vires* as an invalid attempt to affect extra-territorial rights -- that is, the rights acquired by the defendants in Ontario and Saskatchewan.

Although the case has been criticized for its ambiguity, there are some significant comments by members of the Court on the nature of jurisdiction over interprovincial rivers. On the one hand the case can be seen as limiting the rights of a province to defend itself against harmful actions to a shared watercourse from an upstream state. On the other hand it seems to suggest that the upstream province might also be restricted in its use of the shared water resource. It would appear, then, that the regulation of this interprovincial pollution is within the jurisdiction of the federal government; however, the position of the Court on this point is not absolutely clear. The two judgements (representing a majority a four judges)[17] striking down the Manitoba legislation both treat the matter of interprovincial pollution as falling within the federal fisheries power. Obviously, though, not all pollution will be caught under this heading, and subsequent cases (discussed earlier) have indicated that the fisheries power will be read restrictively. Moreover, in the context of diversions, the fisheries power does not provide an adequate basis for federal control of interprovincial water quantity concerns.

There are, however, suggestions of a broader federal role implicit at least in the judgement of Pigeon, J., writing for three members of the majority. While in his view Manitoba cannot legislate away extra-provincial rights existing in Ontario and Saskatchewan, he also holds that it is:[18]

> equally impossible to hold that Saskatchewan and Ontario can license the contaminant discharge operations so as to preclude a legal remedy by those who suffered injury in Manitoba ...

When taken together with his statement that "the basic rule is that general legislative authority in respect of all that is not within the provincial field is federal",[19] this suggests a broader basis for federal jurisdiction in interprovincial water management than one rooted merely in the fisheries power. The most probable constitutional basis for such an approach is the so-called POGG power referred to earlier, and more particularly the national dimensions branch of the doctrine. I will return to this issue in the following section in relation to the Inquiry on Federal Water Policy.

STRUCTURING SHARED RIGHTS AND OBLIGATIONS

The basic constitutional framework for water management in Canada has been set out above. It is one that is characterized by a shared, but by no means precise, division of responsibility between the federal and provincial levels of government. The ambiguities in this area are no more pronounced than in dealing with interprovincial waters. Jurisdictional ambiguities are not new to Canadian federalism of course, and the typical reaction of the Canadian federal system to such problems is to avoid direct confrontation. This means avoidance of judicial resolution of the problems and the negotiation of compromises in federal-provincial -- or occasionally, interprovincial -- agreements. This section will examine the legal status of such agreements and the means through which they may be enforced -- including the emerging possibility that individual citizens may have some enforcement powers. It then briefly examines the legal situation that arises if there is a failure to negotiate such agreements where interjurisdictional water issues are in dispute..

Intergovernmental Agreements

Intergovernmental agreements have generally served the Canadian federation well, but they have also had the effect of postponing judicial pronouncements that could have clarified the scope of federal and provincial powers; this has certainly been the case , for example, with respect to water management. Perhaps the best-known illustration of such an approach is the Apportionment Agreement[20] for prairie rivers and the Prairie Provinces Water Board (PPWB) which administers it. That Agreement effectively removed to the political arena some significant legal questions concerning, for example, the rights of a downstream province to a minimum flow from a shared river and, conversely, the obligations of an upstream province to pass on a certain quantity of water. It is not impossible, of course, that the courts could have dealt with such issues -- certainly American courts have on occasion intervened in such disputes, albeit with some reluctance.[21] However, my impression is that most Canadian water managers would be extremely reluctant to see such water management issues in effect judicialized and become the subject of litigation -- and indeed this hesitancy is probably reflective of a more general reluctance by Canadians to submit disputes to the vagaries of litigation.

In the result, we have in place a number of important federal-provincial agreements across Canada dealing with the use of water resources, with many of the more important ones touching on water diversions. Sometimes these agreements also touch on Canada's international obligations -- as with the Columbia River, the Skagit River, the Lake of the Woods, the Great Lakes and so on. In other agreements the issues addressed are purely domestic in scope -- as with the PPWB and the Ottawa River Regulation Planning Board. And, occasionally, interjurisdictional issues are raised although the waters affected are purely intra-provincial; this can arise because of a federal interest in the waters in question. Thus the federal interest in aboriginal lands affected by the Churchill diversion in Manitoba gave rise to the Northern Flood Agreement. It is quite possible, then, that a major diversion of water in Canada would be accompanied either by a new intergovernmental agreement or by effects on existing intergovernment agreements.

As to the legal status of intergovernmental agreements, it is perhaps not surprising that the general reluctance exhibited by Canadian governments to have clear legal boundaries drawn in many areas of shared federal-provincial interest should be reflected in the agreements designed to finesse these legal uncertainties. The legal nature of some important intergovernmental agreements dealing with water is highly ambiguous; and indeed some public servants seem to regard this ambiguity as a positive aspect. The essential point for water managers is that the agreements work; a more precise and legalized approach could, in their view, be detrimental to the conclusion of such agreements in the first place.

I have some sympathy with this view -- which is often summed up in the old saw, "If its not broke, don't fix it" -- and I am especially sensitive to the problems that can be created by the application of legalistic approaches to problems that are essentially political in nature. However, like it or not, the legal element in interjurisdictional water management is likely to increase in the future. This is so for at least three major reasons: firstly, we can expect, at least in the West, more rather than fewer strains on existing interprovincial arrangements. As water shortages increase as a political problem, it seems to me inevitable that parties will more and more re-evaluate their strict legal rights and obligations. One can see this to some extent even in the PPWB, which has been the model for a consensual non-litigious approach to water management. On at least one recent occasion, for example, the government parties to that agreement decided to seek legal advice on their respective rights under the Apportionment Agreement, pursuant to a disagreement over its correct interpretation. Ultimately the dispute was settled through negotiation, but this result can hardly be predicted with any confidence for other basin disputes where the history of cooperation underlying the PPWB is absent.

Secondly, even if *governments* can agree to resolve differences without recourse to litigation, a recent decision of the Supreme Court of Canada (discussed below) suggests that in some cases, regardless of the wishes of governments, private individuals may be able to initiate judicial review of the operation of intergovernmental agreements.

A final reason we are likely to see an increase in the legal element of water disputes relates to the difficulty that has become apparent in attempts to reproduce the PPWB model. This is most obvious with respect to development of the Mackenzie, where suggestions of an agreement modeled on the PPWB have yet to bear fruit. In these circumstances the pressure will grow on the federal government to exercise its arguably existing jurisdiction with respect to interjurisdictional waters. This call for a greater federal voice on water issues has surfaced from time to time in the past -- as illustrated by the pressure for a national environmental mandate that gave rise to the *Canada Water Act*.[22] One suggestion for a more activist federal role with respect to interprovincial water matters is that proposed by the Inquiry on Federal Water Policy. Even if such federal initiatives are not undertaken, there still remains the possibility of litigation aimed at specific provincial actions affecting shared waters, relying upon some of the suggestions in the *Interprovincial Co-operatives* case discussed earlier.

In examining the legal nature of intergovernmental agreements, one can distinguish at a first level between those agreements that have acquired some constitutional status and those which have not. One example of the former which has direct implications for water management is the Natural Resources Transfer Agreements which transferred ownership of public lands (including water) to the prairie provinces in 1930.[23] Clearly such agreements are both binding and enforceable. The exact status of such agreements does raise some legal questions, but they are not of pressing importance for water managers. For obvious reasons, however, constitutional entrenchment of most intergovernmental agreements is not a feasible or desirable possibility.

The great majority of intergovernmental agreements, then, will be of the non-constitutional variety. Beyond this how do we characterize such agreements, and, more specifically what is the legal content of the undertakings they contain? Are they, for example, only moral commitments, or do they impose binding obligations on the parties? While it is difficult to generalize about them, most intergovernmental agreements with respect to water management seem to carry a mix of what might be called political aspirations and terms that connote more traditional obligations familiar in private contracts. Typical of the latter, for example, are terms dealing with the allocation of costs in shared-cost programs, while the former might include the following provision from the PPWB Master Agreement on Apportionment:[24]

> 6. The parties mutually agree to consider water quality problems; to refer such problems to the Board; and to consider recommendations of the Board thereon.

It might be argued that the sort of political undertakings described above may be difficult to enforce but nevertheless constitute valid legal obligations. Even if one were to accept this assessment, there are a number of clauses in major interjurisdictional water agreements that clearly are without legal effect because of their very aims. Again, looking at the PPWB Master Agreement on Apportionment, one clause in that agreement attempts to bind the various parties to maintain legislation giving jurisdiction to the Federal Court over any disputes arising out of the agreement.[25] Given that this clause -- if it were to be enforced asa matter of law -- would violate certain constitutional conventions which prohibit fettering the power of future legislatures, it must be considered to be without legal effect. (A similar clause in the 1943 Ottawa-Quebec agreement on the generation of power on the Ottawa River would meet the same fate were it tested in court.[26])

In principle then, many of the provisions one encounters in federal-provincial contracts are by nature unlikely to give rise to legal obligations. But what of those provisions -- such as the allocation of expenses of a program -- that are more reminiscent of private sector contractual clauses? It does seem as if courts are willing to treat such undertakings on the same principles as they would private contracts. There are, admittedly, some possible problems of finding a forum for resolution of any disputes. However, the federal government and all provinces except Quebec have agreed by means of reciprocal legislation to accept the jurisdiction of the Federal Court in intergovernmental disputes, a jurisdiction that does not exist in the various superior courts of the respective provinces. While theoretically it is possible for a province to repeal this legislation at any time, and thereby deprive the Federal Court of jurisdiction (although there would be some doubt as to whether it could be deprived of jurisdiction in a proceeding already initiated), in fact this situation seems unlikely to pose a serious threat. Historically the refusal of one province to submit to litigation when confronted with an intergovernmental dispute not susceptible to political resolution has not been a problem in Canada. Certainly a provision such as that in the United States Constitution which gives the Supreme Court original jurisdiction in disputes between states would make things neater for a lawyer, but as a practical political matter the issue of provinces consistently breaching agreements has been a moot point. The more serious question has revolved around the conclusion of such agreements in the first place, a problem dealt with further on in this paper.

If the litigation of interjurisdictional water agreements by governments is unlikely to be a practical problem for water managers, why should water managers concern themselves with the legal niceties of such matters? In practice, as most public servants quite rightly point out, disputes in this area are in practice settled by political means. While, given the possibility of increased pressures on water supplies, especially in the West, I am not sure that this will continue to be the case, there is another, more compelling reason why such agreements are more likely now to become subject to judicial scrutiny; this is the increased possibility of review at the instance of private citizens.

The ability of individuals to challenge administrative acts of governments has been the subject of important judicial comment recently. In the case of *Finlay* v. *The Minister of Finance of Canada*,[27] a private individual sued for a declaration that certain payments by the federal government to the Government of Manitoba were illegal. Essentially the applicant maintained that the distribution of benefits under Manitoba's social assistance legislation was not in compliance with the relevant provisions of the *Canada Assistance Plan*,[28] a federal statute which provides the basis for the federal-provincial cost-sharing arrangements. In effect then, the applicant sought standing to challenge the administration of a federal-provincial agreement. While the right of a private citizen to challenge the constitutionality of legislation in the appropriate circumstances has been accepted for over a decade in Canada,[29] it was not clear whether a citizen -- who did not possess a special interest in the matter -- would have the right to challenge such an *administrative* action by government. The *Finlay* case states clearly that such actions are open to question in the right case -- the primary requirement of which is "that there should be no other reasonable and effective manner in which the issue of statutory authority .. may be brought before a court."[30]

What are the implications of this decision for water management agreements? It should be pointed out firstly that the *Finlay* case could be read narrowly as dealing only with agreements that are subject to explicit statutory arrangements, rather than, say, a loose legislative provision allowing a Minister to enter into agreements in a certain area as he sees fit (as, for example, with section 4 of the *Canada Water Act*). If this is the case, then most (but certainly not all) intergovernmental water management agreements might be immunized from reviews initiated by private citizens. Moreover, granting the necessary standing to challenge government action does not of course mean that the challenge itself will be successful. (Indeed in the leading constitutional cases noted above where standing was granted, the applicants did not succeed on the merits.)

My reading of the *Finlay* case, however, is that even where there may not be detailed statutory provisions, a court might be willing to grant a concerned citizen the right to challenge the operation of a statutorily authorized intergovernmental agreement, despite the feeling on the part of public servants that the issue of how an agreement is carried out should be a subject for political rather than judicial processes. Thus the broad statement by Le Dain, J., writing for a unanimous court in *Finlay*, that:[31]

> where there is an issue which is appropriate for judicial determination the courts should not decline to determine it on the ground that because of its policy context or implications it is better left for review and determination by the legislative or executive branches of government.

Sharing Water Resources in the Absence of Agreements

The above discussion addressed the legal problems associated with intergovernmental agreements but what of the legal situation where no agreement can be negotiated? This seems to me to raise two possible sets of legal problems: firstly, those associated with the possibility of "unilateralism", that is the constraints, if any, placed on one (most likely, the upstream) province in dealing with shared water resources; and secondly, those associated with an attempt by the federal government to impose a solution where one cannot be negotiated.

As to the first issue, it seems clear, on the basis of the *Interprovincial Co-operatives*[32] case discussed *supra*, that a province will be constrained in some respects as to how it deals with shared water resources. The exact nature of these constraints remains to be defined, but if one looks at the experience of the United States Supreme Court in this regard,[33] it may well be that a court presented with a dispute concerning the shared use of interjurisdictional waters would be influenced by the principles that have grown up in international law in this respect, and most especially by the principle of equitable utilization, which has received wide support in both jurisprudence and legal writing.

It might be of special interest to Canadian water managers that an important factor in American courts' evaluations of what is equitable is the past conduct of the parties involved. Thus, what is regarded as an essentially "political" -- or in any case a revocable -- agreement may have legal implications in another sense, that is as evidence of what is equitable. For example, even were the PPWB's Master Agreement on Apportionment to be revoked, the principles contained in it -- such as the requirement to pass on half the natural flow to the downstream province -- might nevertheless continue to have important legal implications, a point which seems to me not fully appreciated by many water managers. There are, again, certain legal obstacles that may arise in raising such a dispute in court, but these do not seem to me to be insurmountable.

As to the second issue -- the possibility that the federal government may impose a solution where a dispute appears not amenable to negotiation, or where negotiations have floundered -- the federal role in interjurisdictional disputes is one that has waxed and waned depending upon the priorities of different federal governments and with the profile of specific water management problems. The most recent proposal in this respect is that of the Inquiry on Federal Water Policy,[34] a proposal that seems clearly to have been influenced by the failure to date to negotiate an intergovernmental agreement on the Mackenzie.

The key recommendation of the Inquiry on this point provides:[35]

> 7.6 Part 2 of the Canada Water Act should be repealed and replaced with provisions to authorize the federal government to assist in resolving disputes between provinces and territories about the use of interjurisdictional waters. These new provisions should authorize federal interventions where:
>
> i) The provincial or territorial governments have made reasonable efforts to reach agreement and have failed, and
> ii) The federal government receives a complaint from one or more affected jurisdictions.
>
> The legislation should provide that, where these conditions are met, the federal resolution of the problem should be based on the recommendations of a board established for this purpose and on which the affected jurisdictions are represented.

I have some qualms -- both legal and practical -- with the Inquiry's proposed solution. I am not convinced, for example, that the proposal overcomes the constitutional objections which have been lodged against the provisions for unilateral federal action in Part 2 of the *Canada Water Act*, and which resulted in the federal reluctance to employ it. The Inquiry feels the proposal could be supported on the basis of POGG, although one would think the absence of any reference to "a significant national interest" as exists in the *Canada Water Act* is at least odd. On a practical note, the structuring of the solution as "a federal resolution of the problem" is neither necessary nor likely to endear the proposal to provincial governments. Nevertheless, it is likely that *some* federal role in resolving important interprovincial water disputes would be supportable under POGG.

The Canadian government's reaction to the Inquiry'srecommendations has just been released in the form of a *Federal Water Policy*.[36] The reaction to recommendation 7.6 is, however, somewhat ambiguous. While the need for some arbitral mechanism to deal with interjurisdictional disputes is recognized, it is not at all clear how far the federal government would go in imposing such a mechanism unilaterally. The *Policy* proposes:[37]

- that steps be taken to develop appropriate procedures so that in cases where the jurisdictions involved have tried but failed to reach agreement, and where the issue has become a major concern to one or more of the jurisdictions, those disputes can be referred to mediation or arbitration; and
- to negotiate with the provinces the development of a mechanism which would allow for the ultimate resolution of interjurisdictional disputes in cases where all other means of reaching agreement have failed.

Obviously the degree to which such an approach has real teeth (as the Inquiry anticipated) depends upon the implementing legislation. To date, we have no hint of when such legislation will be forthcoming.

ENDNOTES

1. See, for example, B. Laskin, "Jurisdictional Framework for Water Management", Resources for Tomorrow Background Papers, Vol. 1 (Ottawa: Queen's Printer, 1961); D. Gibson, "The Constitutional Context of Canadian Water Planning", (1969) Alta. L. Rev. 71; G.V. LaForest, "Interprovincial Rivers", (1972) 50 Can. Bar Rev. 39; D. Alhéritière, La gestion des eaux en droit constitutionnel canadien (Québec: Editeur officiel du Québec, 1976).

2. *Constitutional Act, 1867*, s.109. This provision was applicable to the original confederating provinces. The prairie provinces did not receive ownership of resources until the Natural Resources Transfer Agreements, enacted through the *Constitution Act, 1930*, 21 Geo. V, c.26 (U.K.).

3. As added by the *Constitution Act, 1982*.

4. Section 92A(4)(b). This in effect allows the provinces to engage in indirect taxation of resources, a mode of taxation which is otherwise prohibited for provincial governments by virtue of section 92(2) of the *Constitution*.

5. *A.-G. Canada* v. *Aluminum Co. of Canada* (1980), 115 D.L.R. (3d) 495 (B.C.S.C.).

6. *Fisheries Act*, R.S.C. 1970, c.F-14, as amended.

7. *Fowler* v. *The Queen*, [1980] 2 S.C.R. 213, at 152.

8. A.R. Lucas, "Comment", (1982) 16 U.B.C. L. Rev. 145, at 152.

9. See Laskin, *supra*, note 1, at 216.

10. This despite the fact that there is no explicit navigation power in the U.S. *Constitution*; the navigation power in the United States has been inferred by the courts from the Commerce Clause.

11. Treaty Between the United States and Great Britain Relating to Boundary Waters, and Questions Arising between the United States and Canada, Washington, 11th January 1909, T.S. 548. The treaty was concluded by Britain, as the Imperial power, on Canada's behalf.

12. Under section 132 of the *Constitution Act, 1867*, the federal government is given the power to implement treaties concluded by the United Kingdom on Canada's behalf -- including the Boundary Waters Treaty. Ironically once Canada gained a treaty-making capacity in its own right, it did not acquire a similar right to implement treaties affecting matters within provincial jurisdiction. Thus, had the Boundary Waters Treaty been entered into by Canada, the federal government arguably would not have acquired the implementing powers it now holds by virtue of section 132. See *A.-G. Canada* v. *A.-G. Ontario* (Labour Conventions), [1937] A.C. 326 (P.C.).

13. *International River Improvements Act*, R.S.C. 1970, c.I-22.

14. Section 2 of the Act defines an international river as "water flowing from any place in Canada to any place outside Canada."

15. The POGG power has different "manifestations" or branches. The test for the national dimensions branch of the doctrine was set out by Lord Simon in the Privy Council as whether "the real subject matter of the legislation ... goes beyond local or provincial concern or interests and must from its inherent nature be the concern of the Dominion as a whole": *A.-G. Ontario* v. *Canada Temperance Federation*, [1946] A.C. 193 (P.C.) at 205.

16. *Interprovincial Co-operatives* v. *The Queen in Right of Manitoba*, [1976] 1 S.C.R. 477, 53 D.L.R. (3d) 321.

17. By Pigeon, J. (in which two other members concurred) and Ritchie, J. The decision was reached by a vote of 4 to 3.

18. *Supra*, note 16, at 358 D.L.R.

19. *Id.*, at 357 D.L.R.

20. Master Agreement on Apportionment, between Canada, Alberta, Saskatchewan and Manitoba, 30 October 1969.

21. *Kansas* v. *Colorado*, 206 U.S. 46 (1907); *Connecticut* v. *Massachusetts*, 282 U.S. 660 (1931); *Nebraska* v. *Wyoming*, 325 U.S. 589 (1945); *Colorado* v. *New Mexico*, 459 U.S. 176 (1982).

22. *Canada Water Act*, R.S.C. 1970 (1st Supp.), c.5.

23. *Supra*, note 2.

24. *Supra*, note 20.

25. *Id.*, clause 8.

26. Agreement of January 2, 1943 between Ontario, Quebec, Hydro-Electric Power Commission of Ontario and Quebec Streams Commission, clause 14. The Agreement is scheduled to the *Ottawa River Water Powers Act, 1943*, S.O. 1943, c.21.

27. *Finlay* v. *The Minister of Finance of Canada* (1986), 71 N.R. 338 (S.C.C.).

28. *Canada Assistance Plan*, R.S.C. 1970, c.C-1.

29. The leading cases are *Thorson* v. *A.-G. Canada*, [1975] 1 S.C.R. 138; *Nova Scotia Board of Censors* v. *McNeil*, [1976] 2 S.C.R. 265; *Minister of Justice of Canada* v. *Borowski*, [1981] 2 S.C.R. 575.

30. *Supra*, note 27, at 369.

31. *Id.*, at 367.

32. *Supra*, note 16.

33. See *Kansas* v. *Colorado*, *supra*, note 21.

34. Canada, Inquiry on Federal Water Policy, Final Report, *Currents of Change* (Ottawa, 1985).

35. *Id.*, at 74-75.

36. Environment Canada, *Federal Water Policy* (Ottawa, 1987).

37. *Id.*, at 33.

INTERBASIN TRANSFER OF WATER:
ECONOMIC ASSESSMENT AND IMPLICATIONS

TERRENCE S. VEEMAN[1]

ABSTRACT

Interbasin transfers of water can be evaluated, from an economic point of view, in terms of efficiency and equity. An interbasin transfer is economically feasible (the least stringent test of economic efficiency) if its social benefits exceed its social costs. This implies, in turn, that the direct and secondary benefits to importing and transfer regions, must exceed the direct and secondary costs to exporting and competitive regions, plus the cost of the water transfer facilities and any environmental or spillover costs of the project. The major methodological and empirical problems likely to be encountered in a feasibility study include: the issue of whether secondary benefits and costs of the project should be considered; the difficulty of assessing the cost of the project to the exporting region when current uses are largely non-consumptive in nature; and the empirical difficulty of estimating extra-market benefits and costs (such as those involving environmental enhancement or damage). The second criterion, that of equity or income distribution, is concerned with the incidence of benefits and costs: that is, who reaps the benefits and who bears the costs. Interbasin water transfers are expected to redistribute income to regions importing water and to impose disproportionate costs on regions exporting water. In the Canadian context, possible adverse costs which might be imposed on northern native communities are of special policy concern.

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INTRODUCTION

The economic assessment of interbasin transfers of water is very much in its infancy. Few, if any, interbasin transfers--particularly those involving non-hydro uses--have been studied rigorously, from an economic point of view, in Canada. At our current state of knowledge, the best that can be done is to outline the proper methodological approach to the economic evaluation of interbasin water transfers, examine the theoretical and empirical problems of estimating benefits and costs which are highly likely to occur, and hazard educated guesses about the suspected economics of transfer from rather fragmentary evidence (associated with historical and current within-basin water projects in Canada and with a few instances of actual or proposed transfers of water in other nations, especially the United States and the U.S.S.R.).

Canada leads all nations in terms of the volumes of water diverted between basins (Quinn 1987). An estimated 96 percent of this interbasin transfer, however, is for hydropower production, a use which is overwhelmingly non-consumptive in nature. This means that nearly all water diverted from one basin (although lost to this basin of origin) is not used consumptively but is returned, largely unchanged in quantitative volumes, to a second river basin. The largest interbasin transfers in eastern Canada are those associated with hydro-electric generation in the James Bay Project in Quebec and the Churchill Falls projects in Newfoundland. In western Canada, the most important interbasin water transfer is the Churchill diversion in Manitoba from the Churchill River to the Nelson River, again for hydropower purposes. The most significant transfer of water for non-hydro purposes occurs in southern Alberta, albeit within the South Saskatchewan system. Irrigation water originally diverted from the Bow River is used, largely consumptively, on lands outside the Bow basin, with remaining return flows returning to the Oldman and Red Deer Rivers. In Saskatchewan, relatively small volumes of water are transferred from the South Saskatchewan River to the Qu'Appelle system, primarily to augment municipal water supply and improve water quality.

Even this preliminary overview of interbasin water transfers in Canada should forewarn us that it is very important to distinguish between different types of interbasin transfers. First, it is critical to distinguish between large-scale transfers involving huge mega-projects and those of a relatively small nature which are likely to involve much smaller magnitudes of economic cost and environmental disruption. Secondly, it is useful for both analytical and policy purposes to differentiate between transfers for hydropower purposes (involving large withdrawals but little consumptive use) and transfers for agricultural purposes (where consumptive use is significant). In the hydropower case, the crucial issues include the relative merits of hydro-electricversus other potential sources of energy, the strength of domestic and particularly U.S. markets for power, and the possibilities of government revenue or rent collection. In the agricultural case one is typically assessing the relative merits of transferring water into a sector which already dominates consumptive use statistics, especially in western North America, but which, paradoxically, is a relatively low-valued user of water at the margin. Finally, interbasin water transfers in Canada could be for domestic purposes or for water export. To date, existing transfers in Canada have been virtually all for domestic purposes.

In this paper, I shall focus more attention on interbasin transfers which would be large scale rather than small, which would involve agricultural and industrial rather than hydropower uses, and which could involve either domestic or export uses. For example, such a transfer could be the possible movement of water from the main stems of the Peace and Athabasca Rivers to augment water supplies in the southern prairies and, perhaps, south of the border in the Ogallala-High Plains region of the western United States.

Major interbasin water transfers of this sort have several economic characteristics (Howe 1979; Fisher 1979; Howe and Easter 1971). They typically have very large economic costs, suspected major environmental costs, and rather inadequate benefit streams. Furthermore, they are typically capital-intensive and involve large transport costs per unit of water (Castle 1983). Two related caveats must be noted: (1) most transfers in Canada to date, as Quinn (1987) notes, have not involved major north-south diversions to drier regions over long distances, but rather "short cuts between proximate water bodies" often using gravity flows; and (2) it is certainly possible to think of lower cost transfers which are much more likely to be candidates for the public agenda than massive diversions from the Peace-Athabasca system--one such prospective diversion being from the Clearwater River, a tributary of the North Saskatchewan River, to the Red Deer River, a tributary of the South Saskatchewan River (Gregg 1983). Where water is diverted over long distances, transfer schemes are generally energy-intensive because of their large pumping and tunnelling requirements. In schemes where power recovery is possible, interbasin transfer may become more viable. A final economic characteristic of interbasin transfers is that they involve critical questions of timing (Fisher 1979). For instance, there may be advantages to delaying massive, costly projects if cheaper alternative sources of water can be used in the meantime or if it is possible that improved information about environmental effects might become available.

The final introductory comment I wish to make is that I believe it is imperative that we assess interbasin transfer projects from an economic perspective. Most proposals for large-scale interbasin transfer have involved engineering solutions to the alleged water scarcity problems of Canada and the United States. It is critical that they be subjected to economic scrutiny. I confess that I start from a position of skepticism concerning massive interbasin transfers: the fragmentary evidence we have on major transfers, particularly those likely to involve irrigation, is that they appear uneconomic--in fact, uneconomic by a very wide margin.

ECONOMIC EVALUATION OF INTERBASIN TRANSFERS

Interbasin transfers of water can be evaluated using two chief criteria for assessing economic performance: efficiency and equity. It is useful, at least initially, to couch these two criteria in terms of the logic of benefit-cost analysis. Benefit-cost analysis, despite its warts, is an operational tool for assessing the general advantages and disadvantages of a particular course of action, policy, or project. The criterion of economic efficiency is partially fulfilled if the social benefits of any interbasin transfer exceed its social costs (that is, the project is economically feasible); further, the interbasin transfer must be less costly than other alternatives for meeting the particular water objective, as well as being a social investment which yields at least as good a rate of return as other potential uses of these investment dollars. The criterion of equity or income distribution, on the other hand, is concerned with the incidence of benefits and costs: that is to say, who reaps the benefits and who bears the costs of the interbasin transfer. Some specific problems of equity will be addressed briefly in a later section of this paper.

Before turning to the question of social benefits and costs of any interbasin transfer and the issue of economic feasibility, it is important to recognize several theoretical and practical difficulties with benefit-cost analysis. First, benefit-cost analysis rests on debatable foundations of applied welfare economics--the Pareto Criterion with (hypothetical) compensation." Second, benefit-cost analysis is essentially a partial equilibrium approach which is more suitable for projects which do not change the whole constellation of output and input prices in a regional economy. Ever since the days of the Columbia River projects, economists have been worried whether really large scale water projects--particularly those associated with the generation of cheap power--could be readily assessed by conventional benefit-cost analysis. More sophisticated and comprehensive approaches to policy analysis now exist, including the social accounting matrix (SAM) amplification of input-output analysis and computable general equilibrium (CGE) models (Gillis et al. 1987). But these models are still in their formative stages and not easily applicable to the analysis of interbasin transfers. Third, traditional benefit-cost analysis has typically focussed on economic efficiency as the primary objective with little or no attention to questions of income distribution. Fourth, benefit-costanalysis emphasizes willingness-to-pay as the basis for benefit estimation, but willingness-to-pay by individuals is conditioned by the current distribution of income and ownership of resources in society. Finally, there are difficulties of incorporating the preferences of future generations in benefit-cost analysis and more general difficulties of dealing with policy problems with planning horizons exceeding 40 or 50 years. Despite these shortcomings, benefit-cost analysis remains the most practical initial methodology for evaluating interbasin water transfers.

In undertaking benefit-cost studies, it is important to: (1) take a social perspective; (2) choose an appropriate accounting stance; and (3) specify the problem at hand correctly and ensure that the full range of alternatives in solving that problem are being considered (see Veeman (1985a) for a brief introduction to these aspects). For example, private engineering firms are likely to undertake a commercial project appraisal of an interbasin transfer in terms of private returns, costs, and discount rates whereas any social evaluation should consider social benefits (including unappropriated benefits), social costs (including uncompensated external or third party costs such as environmental damage), and a social rate of discount. For water transfer mega-projects involving impacts in two or more provinces, a national accounting stance would be warranted; in smaller transfer projects, a provincial accounting stance may be the most appropriate.

An interbasin water transfer can be shown to be economically feasible (the least stringent test of economic efficiency) if its social benefits exceed its social costs. In other words, the transfer project is feasible if its net social benefits (in present value or discounted terms) are positive or if its benefit-cost ratio exceeds unity. In assessing economic feasibility of any interbasin transfer, it is important to remember that there would be economic impacts not only in the zone of origin from which water is diverted and the zone of destination in which water is ultimately used, but also in any zone through which water is transported and in any zone or region whose output is competitive with that in the zone of destination. Using Fisher's (1979) terminology and notation which, in turn, is largely based on pioneering work on interbasin transfers by Howe and Easter (1971), an interbasin transfer project is economically feasible if:

$$(DB_M + SB_M) + (DB_T + SB_T) > (DC_X + SC_X) + SC_C + TC$$

where DB is the direct (or primary) benefit from using the water, DC is the direct cost (of foregone water), SB and SC are secondary benefits and costs (if they can be legitimately included), and TC is the total (social) cost of the water transfer system, including private or project socio-economic costs associated with community disruption. The subscript M refers to the region importing water (or the area of water destination); X refers to the region exporting water (or the zone of water origin); T refers to the region through which water is transferred: and C refers to a region whose output is competitive with M and which could suffer decreased production and/or lower ouput prices because of M's increased economic activity. The preceding inequality states that the direct and secondary benefits, to importing and transfer regions, must exceed the direct and secondary costs, to exporting and competitive regions, plus the cost of the water transfer facilities and any environmental or other spillover costs of the project (Fisher 1979). Two points of clarification are in order: (1) the direct benefits in M and T could include both market-related benefits, as with irrigation, or extra-market benefits, as with the benefits of recreation or environmental enhancement; and (2) there are serious concerns, to be discussed in more detail later, as to whether secondary benefits and costs are legitimate efficiency items or merely income transfers which effect income distribution within the accounting framework but not efficiency.

The fact that an interbasin transfer project passes the limited test of economic feasibility (that its social benefits exceed its social cost) is a necessary but not a sufficient condition that the project is economically efficient. In the first place, the transfer project must be compared with other alternatives to the water management problem to check that interbasin transfer is, in fact, the cheapest alternative. In formal notation, this is ensured if:

$$TC + [(DC_X + SC_X) - (DB_T + SB_T)] < TC_A$$

where TC_A is the cost of the best alternative for providing water (Fisher 1979). That alternatives to interbasin transfer be examined is critical. My distinct impression of the water resource management literature over the past fifteen years is that there has been increasing recognition by resource economists and water planners in Canada, the western United States, Australia, and elsewhere that water supply problems are very likely to be met more cheaply by programs of demand management than by policies of supply augmentation (via dams, diversions, and transfers). Demand management and water use conservation programs involve water pricing, non-price rationing schemes, and institutional improvements in systems of water rights to permit greater flexibility in shifting water to higher-valued uses (Veeman 1985b). Proponents of interbasin transfers, particularly for agricultural, industrial, or municipal purposes, tend to forget these potential alternatives. The final efficiency test for any project, including interbasin transfer, is that it yields as high a return as alternative social investments in the economy.

MAJOR DIFFICULTIES IN ESTIMATING BENEFITS AND COSTS

There are many conceptual and empirical problems in implementing the evaluation methodology outlined in the preceding section. I wish to highlight five such problems: (1) the issues involved in estimating benefits in M, the zone of destination; (2) the problem of estimating costs in the zone of origin, particularly the opportunity cost of the water which is being transferred; (3) the long-standing controversy of whether secondary (or indirect) benefits and costs should be included in water project evaluation; (4) the problem of displaced economic activity in any zone competitive with the water importing region; and last, but certainly not least, (5) the problem of estimating environmental or extra-market benefits or costs that might be associated with any potential water transfer.

Estimating Benefits in the Water Import Region

Many of the benefit streams associated with an interbasin transfer can be evaluated in terms of market prices. Hydropower production can be valued in terms of the domestic or export market price for power. Similarly, irrigation output can be valued in terms of market prices, correcting these where necessary to eliminate any distortions and to reflect the true societal scarcity value of each output. Since benefits (and costs) are typically projected ahead using constant dollar or real prices, it is only permissible to include any anticipated change in real price levels in the analysis. For example, many analysts would expect the historical trend in real grain prices to be slightly downward whereas (notional) amenity service values are expected to increase in the future relative to the general price level.

Major interbasin transfers within western North America must be justified primarily in terms of irrigated agriculture. Recent studies of irrigation expansion using within basin water, in southern Alberta and central Saskatchewan (based on primary benefits and ignoring secondary benefits) yield benefit-cost ratios near, or below, unity. It is hard to escape the conclusion that more costly transfers of water from the main stems of the Athabasca and Peace Rivers to the southern prairies would fall far short of economic feasibility.

The best empirical evidence on the economics of water transfer for agricultural purposes comes from an American study of prospective water importation from the Mississippi and Missouri Rivers onto the Ogallala-High Plains region of the western United States (Frederick and Hanson 1982; Beattie 1981; Lansford et al 1983). In this region, the underlying groundwater aquifer is being depleted and major reversions from irrigated to dryland agriculture are anticipated. The expected costs of importing water into this region, ranging from \$352 to \$880 an acre-foot (in 1977 U.S. dollars) are high--in part due to the long canals and considerable pumping involved. These costs dwarf any reasonable expectation regarding irrigation water returns (agricultural marginal value products being in the \$20 to \$45 range). As Beattie (1981: 294) concludes: "Clearly, from the point of view of the U.S. as a whole, massive investment to augment the declining Ogallala is not economically efficient--not now or in the foreseeable future." In a New Mexico study, Landsford and co-authors (1983) also reach the conclusion that water importation is not a viable policy option and that voluntary water conservation by farmers would be the preferred alternative.

The Opportunity Cost of Water in the Exporting Zone

The export of water from the zone of origin may cause various uses of water to be foregone, now or in the future, in that zone. The values of these foregone uses, termed opportunity costs, are also valid costs of the water transfer project. If the foregone water uses are associated with current industrial or agricultural activity, the estimation of such values is relatively straight-forward. Difficult estimation problems arise, however, where the foregone water uses are non-consumptive in nature and are associated with the maintenance of ecological regimes in and along northern rivers. Such opportunity costs associated with ecological disruption could also be conceived of as environmental costs of the project.

Most interbasin transfers in Canada involve transfers from northern river basins with relatively sparse populations and limited industrial and agricultural activity. Residents in such basins may feel that they may need water some 30 or 40 years in the future to service larger populations and greater economic activity. The opportunity costs of water in these circumstances may need to include, in addition to the discounted value of expected economic uses of water, some reservation value or option demand component--a willingness to pay on the part of an uncertain user to retain the possibility of using water at some future date.

Current withdrawals and consumptive uses of water from northern river basins may be slight at the moment. There are major difficulties, however, in assessing whether or not there might be surplus waters available for potential transfer from such basins. The chief problem is in assessing the minimum flows that are needed to maintain ecological regimes and habitats associated with northern rivers. In fact, it is often argued that any diminution of the flows of the immense northern rivers or disruption of their yearly cyclical flood patterns could severely disrupt the fragile northern ecosystems on which native northerners, in particular, currently base part of their livelihood.

Secondary Benefits: To Include or Not to Include?

The question of secondary benefits has been the most troublesome and controversial aspect of the assessment of water resource projects, particularly those involving irrigation expansion, in western Canada. This problem is an old one in the resource economics and benefit-cost literature (Ciriacy-Wantrup 1955), but equally a persistent one (Howe 1986). There is every reason to anticipate that this "hydra will raise its head" yet again in the evaluation of interbasin transfers.

Secondary or indirect benefits refer to the spin-off economic activity which either stems from the primary purposes of the project (forward linked activity such as further transporting or processing of expanded irrigation production) or is induced by the project (backward linked activity such as the additional net incomes generated in input supply industries to irrigation or recreation). Since the 1950s, economists have been very reluctant to justify projects in terms of their secondary benefits. Secondary benefits of a project can only be counted as legitimate efficiency benefits of the project (that is, as actual net gains in economic activity and not merely transfers of income) if resources in the project region are chronically unemployed over the life of the project. Where labour and capital resources are fully employed, secondary benefits should not be included in the efficiency analysis. If cyclical unemployment of labour occurs and the project is being built in depressed times, it is appropriate to scale labour costs of the project downward using appropriate shadow values for labour that are less than the wage being paid.

If secondary benefits can only be counted as legitimate efficiency benefits in exceptional circumstances, this is not to argue that they are irrelevant in project evaluation. Their proper role relates to regional income distribution, repayment and pricing. If beneficiaries of a project are called upon to pay some part of the capital costs of a project, it is useful to know the relative magnitudes of primary and secondary benefits to derive a fairer basis for repayment.

Potential Displacement of Economic Activity in Competing Regions

The interbasin transfer of water will spur increased economic activity in the zone receiving water (M) and, in some cases, in the zone through which water is transferred (T). A potential cost of the interbasin transfer, however, is that the increased economic activity in zones M and T may come at the expense of displaced economic activity and/or reduced output price levels in any zone (C) which is competitive with zone M or T. For example, increased sugar beet production in southern Alberta on land irrigated by a (hypothetical) interbasin transfer could lead to either reduced sugar beet production in southern Manitoba or to lower sugar beet prices for Manitoba farmers. Such adverse impacts (SC in zone C in the initial feasibility inequality) must be considered as (secondary) costs of the transfer.

Environmental Impacts: Extra-Market Benefits and Costs

There appears to be a growing awareness that interbasin transfers will have major environmental impacts, particularly on the cost side. To be sure, some water transfers on the prairies could involve the generation of environmental benefits--for example, in river basins such as the Battle or Souris which have periods of very low flows. The construction of reservoirs in a transfer system may yield recreation and fishing benefits which must be imputed. However, most attention has been placed on the significant environmental costs which appear to be associated with interbasin transfers.

Environmental costs range from adverse impacts on ecosystems, particularly in the exporting zone, to possible third party costs associated with the construction of transfer facilities. The range of possible third party costs associated with water transfer is indeed wide: reduced habitat, mercury accumulation in reservoirs, lost wetlands, scouring of channels, species transfer, loss of wild river benefits, possible micro and macro climatic change, and so on. Such spillover or uncompensated costs, termed technological external diseconomies, should be included in any benefit-cost study. Economists are slowly increasing the range of extra-market effects which can be estimated in quantitative terms. The art of extra-market benefit estimation is most advanced for outdoor recreation, hunting, and fishing benefits. More studies are now appearing on the benefits of pollution control or, alternatively, on the damage due to pollution.

The estimation of extra-market benefits for recreation and amenity services involves the imputation of demand curves using information on willingness to pay. In the contingent valuation approach, users are asked to reveal, through direct survey or questionnaire techniques, their willingness to pay for services. Alternatively, in indirect techniques such as the Hotelling-Clawson-Knetsch approach, willingness to pay is imputed from travel cost, population, and visitation information. The estimation of environmental damage often involves a two-step process: first, the determination of the physical magnitude of damage and second, the imputation of a dollar value to this physical damage (Fisher 1981).

A special case wherein potentially large external costs may be imposed on society is associated with the loss and transformation of unique natural or scenic environments (Krutilla and Fisher 1975). In this case society is faced with a mutually exclusive choice between a development use and a preservation use. Some interbasin transfer projects may involve such a mutually exclusive choice between preserving a unique wild river, species, or natural area and "developing" that river or area for water transfer. The demand for the use of a unique natural area with very limited or no substitutes will be characterized by significant consumer surplus and the existence of considerable option demand. Great caution is dictated in irreversibly developing such unique phenomena of nature.

SELECTED EQUITY ISSUES

Social decisions about interbasin transfer projects should not be taken solely in terms of efficiency considerations. Policy-makers must also assess whether transfer projects will improve among individuals and the regional distribution of income.

In terms of equity impacts, interbasin water transfer typically involves a major redistribution of income to the region receiving the water (Castle 1983; Beattie 1981). This is particularly the case in both Canada and the United States where taxpayers at large might be expected to underwrite most, if not all, of the costs of transfer projects. Thus, water projects desired at the local or regional level may not necessarily be in the wider public interest (when using a national or provincial/state accounting stance). Under these circumstances, "water often becomes a convenient political tool for doing something for one's constituents" (Castle 1983: 10). Indeed, Howe (1987) has demonstrated that for the Colorado-Big Thompson Project in Colorado, the benefit-cost ratio from the national viewpoint was substantially less than one, but the benefit-cost ratio from the regional viewpoint was 11. Back of the envelope calculations for the Three Rivers Dam on the Oldman River in Alberta are remarkably similar to the Colorado case--a provincial benefit-cost ratio slightly less than one, but a regional ratio, depending on assumptions, in the range of 5 or 10 to 1. It is no wonder that regional residents in Colorado or southern Alberta greatly favor water projects.

Generally, areas of water origin--the zones exporting water--bear a disproportionate share of the costs of an interbasin transfer. In nearly every case, areas of water origin oppose interbasin water transfer (Quinn 1973). This is a concern in western Canada because, as a rule, income levels in northern river basins from which water is likely to be diverted are lower than income levels in potential water-receiving regions to the south. Further, there should be a special policy concern that isolated northern communities--often largely native communities--may be particularly adversely affected by water transfer projects (unless compensating land claims are implicitly associated with the project). No doubt we need further research to establish more conclusively the role that northern waters play in the maintenance and sustenance of the ecological and habitat regimes on which northern renewable resource exploitation and the livelihoods of many native northerners seem to depend.

CONCLUSION

Interbasin water transfers can be evaluated in terms of efficiency and equity, two criteria often used to evaluate economic performance. Benefit cost analysis, despite several drawbacks, is at least an operational starting point for assessment. An interbasin transfer is economically efficient if its social benefits exceed its social costs and if it is the least cost alternative to the water problem at issue. Economic assessment involves the study of the economic impacts of the interbasin transfer in the region from which water is exported, in the region receiving water, in regions through which water is transported, and in any region which produces competitive output.

Major methodological and empirical problems arise in the estimation of benefits and costs. Among the more serious are the difficulties of estimating benefits in the water-receiving zone, the problem of estimating the opportunity costs of water in the zone of water origin, the controversial role of secondary or indirect benefits, the issue of estimating displaced economic activity in competitive regions, and the problem of estimating extra-market values associated with environmental impacts.

In terms of equity or income distribution, interbasin transfers nearly always redistribute income to regions receiving water while imposing disproportionate costs on the regions from which water is transferred. In Canada, serious equity concerns may occur for northern native communities whose economic livelihood and way of life may be adversely affected by major transfers.

No doubt we will continue to see Canadian-style diversions largely for hydro purposes and perhaps the study of small scale, short distance diversions for other water use. Massive north-south interbasin transfer schemes do not seem a strong likelihood in the rest of this century nor even in our lifetime. It is instructive that the Soviet Union, under the political leadership of Mikhail Gorbachev, has indefinitely shelved the major north-south transfer schemes in Siberia-Central Asia and eastern Europe. In Canada, it is fortunate that we have time to improve through research our knowledge of massive water transfer schemes.

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WORKSHOP SESSION

INTERBASIN TRANSFER OF WATER: IMPACTS AND RESEARCH NEEDS FOR CANADA

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ISSUES ON INTERBASIN TRANSFER IN CANADA

SUMMARY OF THE WORKSHOP PROCEEDINGS

JOHN FITZGIBBON[1]

Introduction

Future water development should be based on the best possible understanding of the nature of the development and its implications for society and the environment. The objective being to develop only those schemes that are economically viable, socially acceptable, and environmentally sound. In order to obtain a broad perspective on the research required to achieve this type of undertaking a series of four workshops were held. These workshops were held subsequent to the papers being presented and to develop an agenda of required research. The workshops dealt with four topics and were provided with introductory terms of reference. (see Table 1)

TABLE 1 THE TERMS OF REFERENCE FOR THE WORKSHOPS

Project planning and design alternatives

Alternatives may include the nature, scale, timing, and other features of a transfer project but should also consider non-transfer alternatives for meeting water demands.

Environmental Monitoring

A general framework for monitoring would include the scope, process, and responsibility for data collection and interpretation, and would identify how monitoring could influence project management.

Operation, Maintenance, and Mitigation

Transfer projects will encounter changing circumstances during and after their construction period. What flexibilities exist for operating, and maintaining a project, for mitigating adverse impacts structurally or otherwise.

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Law and Public Involvement

The identification of jurisdictional responsibilities and their application through laws and regulations remains fuzzy, as, in many cases does provision for public involvement in project planning and assessment.

Project Planning Summary

The workshop on project planning expressed the idea that the planning process for interbasin transfers should be more proactive of a wide variety of concerns with respect to the transfer project as well as alternatives to transfers.

This is evident in the identification of a broader need in the area of evaluation of the project feasibility. Project justification should be based on broader economic principles such as the equitable distribution of costs and benefits between the donor and recipient basins. Social and environmental concerns should be placed on an equal basis with engineering and economic issues in the evaluation process. Impact assessment should act as a tool in the planning process to not only identify adverse effects but also specify mitigative measures to be incorporated in the project.

Long term implications should be considered in the planning process. These would include climatic change, technological change, and others. This would be done through more rigorous analysis of the risks of failure of a project.

Given that many transfers impact upon more than one jurisdiction there needs to be some more effective means of interjurisdictional coordination for planning purposes.

Alternatives

In the area there are a great many water management strategies that need to be considered which can augment, extend, or conserve existing water supplies thus averting or delaying the need for interbasin transfers. These include demand management through pricing or improvement of efficiency of use, development of technologies for water conservation, elimination of institutionally created shortages, and through growth management in areas of limited water supply.

Environmental Monitoring Summary

The workshop dealt with two areas of environmental monitoring with respect to interbasin transfers. These are monitoring of ambient conditions and project effects monitoring. The issues that arise in the area of monitoring are those of appropriate data, data quality, and responsibility for data collection, interpretation, and fiscal responsibility for support of monitoring.

Agreements for the development of monitoring of both ambient and project affected conditions should be made as part of the project development and planning process. This would require definition of lead agencies, standards of performance for data collection, information sharing, and funding. Consideration for the identification of unexpected adverse effects and the monitoring of the effectiveness of mitigation should be included as a flexible part of the monitoring agreement. There is also need to deal with the legal implications of these monitoring programs such as the definition of what constitutes due care in the monitoring process.

Mitigation Summary

The mitigation of adverse unintended effects is an important aspect of the ongoing management and development of a transfer project. These effects fall into the three areas of environmental, social, and economic effects. In the area of environmental effects these effects are seen to be effects on the morphology of the river system both the receiving system and donor system; water quality effects and sediment quality effects in both the impondments and in the donor and receiving river systems; biological effects including loss of habitat and associated species and the transfer of undesirable disease and flora and fauna between basins.

In the social area the adverse effects are seen to be loss of traditional ways of life, especially in the north-south transfers and destabilization of the community especially during the construction period.

In the area of economic effects the areas of adverse effect tend to be in the donor basins. The transfers often mean the loss of income from water related activities such as fishing, and tourism.

Law and Public Involvement

The workshop on the law and public involvement considered that these two areas were related. They were not necessarily dealt with together.

In the area of public involvement it is being recognized that there is a trend toward a more participatory process of development. Incorporating this trend into the development of interbasin transfers raises several issues. The public should be recognized as being a complex of various stake holders. Each of these needs to be dealt with differently. The rationale for public involvement needs to be clear and the role of the stake holders in the process needs to be defined so that the process is truly one of valid involvement rather than one of co-option. The timing of public involvement is also critical in that if undertaken at the appropriate time in the planning process it can prevent polarization of views and create a climate of mutual respect and form the basis of negotiation. Public involvement should extend to the post-development phases of a project so that problems do not arise in the management of the project.

In the area of legal issues there are significant concerns with respect to the rights of native peoples to water. This needs to be addressed not only by the federal government but also by the provincial governments. A second major area of concern is that of the settlement of interjurisdictional disputes over transboundary waters. At the present time the process is one of settlement between the disputing parties. There needs to be a process of mediation to facilitate the resolution of these matters.

Recommendations

Project Planning Recommendations

1) Research is needed to resolve the problems associated with the allocation of water for instream use in any water pricing policy.
2) Research is needed to better understand ecological processes and the impacts of interbasin transfer on both the donor and recipient basins.
3) Research is needed to better quantify the potential social, environmental, and faunal transfer impacts resulting from interbasin transfers.
4) Research is needed to establish procedures for risk analysis as a means of evaluating the consequences of failure.
5) More activity is needed in the area of policy research.

Monitoring Workshop Recommendations

1) Research is needed to better define the legal basis for and implications of compliance monitoring of interbasin transfers.
2) Research is needed into the monitoring of large systems that are effected by significant interbasin transfers. This research should include not only flows but quality. An example would be the monitoring of the Saskatchewan - Nelson system.
3) Research is needed in the monitoring of significant events since major effects may be associated with conditions which occur infrequently. This would provide for improvement of

prediction of adverse effects for future developments.

4) Research is needed on the selection of indicator species in holistic systems monitoring. The relationship of indicator species to ecological processes needs to be better understood.
5) Monitoring systems need to be developed to deal with the effects on a basin scale rather than a site or project scale.
6) In particular in the north there needs to be development of socio- economic monitoring systems that can provide baseline or background information against which large scale projects can be evaluated.

Mitigation and Management Workshop Summary

1) Research is needed into the development of means of mitigation of adverse effects of transfers on ecosystems.
2) Research is needed on mitigating the effects of transfers on productivity of effected systems.
3) There is a need for the development of a process such as that of an ombudsman's office to deal with mitigation problems.
4) There is a need for more interdisciplinary meetings to deal with the complexities of developing environmentally and, economically sound, and socially acceptable water management projects.
5) There is a need for long term basic research funding.
6) N.H.R.I. should be encouraged to undertake research into the mitigation of the impacts of interbasin transfers.

Law and Public Involvement Workshop Summary

1) Research is needed to develop procedures for more effective involvement of the public in the project planning phases of interbasin transfer projects.
2) Research is needed in the area of native water rights.
3) Research is needed into the development of more effective processes of interjurisdictional dispute settlement.
4) Research is needed in the areas of enforcement, compensation/mitigation, and post-approval public involvement in the management of transfer and other water development projects.

Conclusion

This symposium has shown that while we have a substantial capacity to develop interbasin transfers of water, there remains yet to be solved a significant number of problems. Solution of these problems will require both new research as well as thorough reflection on our experience to date. It is important that this work be done systematically rather than haphazardly in response to issues as they arise. The need is for a well-formulated on-going research program.

In addition, it is recognized that there is a need to bring together all the sciences and social sciences that can contribute in an interdisciplinary context to meet the challenges of these complex problems.

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